Fishery Data Series No. 95-8

Stock Status and Rehabilitation of Chena River Arctic Grayling During 1994

by

Robert A. Clark

July 1995

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES NO. 95-8

STOCK STATUS AND REHABILITATION OF CHENA RIVER ARCTIC GRAYLING DURING 1994

by

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ABSTRACT

Stock status of Arctic grayling *Thymallus arcticus* in the lower 152 km of the Chena River was described by population abundance, age composition, size composition, recruitment, and survival rate estimates during 1994. In July of 1994, estimated abundance of Arctic grayling in the Chena River was 44,375 fish (SE was 2,964 fish) ≥ 150 mm FL. Age 4 Arctic grayling were strongly represented in the Chena River, representing 34.1 percent of fish ≥ 150 mm FL. Stock-size Arctic grayling (≥ 270 mm FL) represented 79.9 percent of fish ≥ 150 mm FL. Annual recruitment between 1993 and 1994 was 13,113 Arctic grayling (SE was 1,183 fish) and annual survival during this period was 76.9 percent (SE was 7.8 percent).

On 7 through 30 June 1994, 61,435 hatchery-reared Arctic grayling (1993 brood year) were released at six locations along the lower 152 km of the Chena River. Mean fork length prior to release was 208 mm (SD was 24 mm) and mean weight was 94 g. Estimated abundance of these fish in the lower 152 km of river during July 1994 was 41,928 fish (SE was 5,105 fish) ≥ 150 mm FL. Estimated abundance of 1992 brood year hatchery-reared Arctic grayling, released in 1993, was 3,699 fish (SE was 307 fish). Survival of 1992 brood year hatchery-reared Arctic grayling from release in 1993 to July of 1994 was 5.7 percent (SE was 0.5 percent). Survival of 1992 brood year hatchery-reared Arctic grayling from July of 1993 to July of 1994 was 11.2 percent (SE was 1.4 percent), approximately seven-fold lower survival than wild Arctic grayling.

Key words: Arctic grayling, *Thymallus arcticus*, electrofishing, population abundance, age composition, size composition, Relative Stock Density, recruitment, survival rate, rehabilitation, hatchery releases, Chena River.

INTRODUCTION

BACKGROUND

The Chena River once supported the largest Arctic grayling fishery in North America. For the 15 year period from 1979 to 1993, the Chena River produced an average annual sport harvest of 12,933 Arctic grayling (Mills 1981a-1994). Average angling effort for all species of fish during this period was 25,005 angler-days (Table 1). As recently as 1984, annual harvests had exceeded 20,000 fish and annual fishing effort (all species) had exceeded 30,000 angler-days. Harvests of Arctic grayling from the Chena River comprised a substantial portion of total Arctic grayling harvests in the Tanana River drainage (Figure 1). However, the status of this fishery has changed since 1984. Recreational harvest of Arctic grayling has declined to historic low levels. Harvest decreased 76% from 1984 to 1985, although angling effort had decreased only 39% (Table 1). Angling effort returned to an average level in 1986, but harvest remained below 10,000 fish. Concomitant with the declining recreational fishery was the decline in Arctic grayling population abundance. Stock assessment projects during 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) documented a decline in population abundance of 49% between these two years. Poor recruitment was the probable cause for a decline in abundance (Holmes 1984, Holmes et al. 1986, Clark 1992a).

During winter of 1986, fishery managers were scheduled to present stock status data (Clark 1986) on the Chena River fishery to the Alaska Board of Fisheries. The Board of Fisheries meeting adjourned before the data could be presented. In spring of 1987, increased concern for the health of the Chena River stock prompted fishery managers to process emergency regulations to reduce harvest. These emergency regulations were:

1. closure of the fishery from 1 April until the first Saturday in June;
2. a 12 inch (305 mm) minimum total length limit; and,

Table 1.-Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1993 (taken from Mills (1979-1994).

	Lower Chena River[a]		Upper Chena River[b]		Entire Chena River	
Year	Angler-days	Harvest	Angler-days	Harvest	Angler-days	Harvest
1977[c]	---	---	---	---	30,003	21,723
1978[c]	---	---	---	---	38,341	33,330
1979	9,430	11,290	8,016	11,664	17,446	22,954
1980	13,850	18,520	10,734	16,588	24,584	35,108
1981	11,763	10,814	10,740	13,735	22,503	24,549
1982	18,818	11,117	15,166	12,907	33,984	24,024
1983	17,568	7,894	16,725	10,835	34,293	18,729
1984	20,556	13,850	11,741	12,630	32,297	26,480
1985	11,169	2,923	8,568	3,317	19,737	6,240
1986	18,669	4,167	10,688	3,695	29,357	7,862
1987[d]	12,605	1,230	10,667	1,451	23,272	2,681
1988[d,e]	16,244	2,686	9,677	1,896	25,921	4,582
1989[d,e]	20,317	7,194	10,014	5,441	30,331	12,635
1990[d,e,f]	18,957	3,494	6,949	945	25,906	4,439
1991[d,e,f,g]	12,547	2,997	8,591	722	21,138	3,719
1992[h]	7,671	0	4,983	0	12,654	0
1993[h]	15,631	0	6,018	0	21,649	0
Averages[i]	15,053	6,545	9,952	6,388	25,005	12,933

[a] Lower Chena River is from the mouth upstream to 40 km Chena Hot Springs Road (Mills 1988). For 1991 through 1993 the Lower Chena River included Badger Slough. Angling effort is for all species of fish.

[b] Upper Chena River is the Chena River and tributaries accessed from the Chena Hot Springs Road beyond 40 km on the road (Mills 1988). Angling effort is for all species of fish.

[c] Angler-days and harvest are computed for the Chena River and Badger Slough.

[d] Special regulations were in effect during 1987 through 1991. These regulations were: catch-and-release fishing from 1 April until the first Saturday in June; a 305 mm (12 inch) minimum length limit; and, a restriction of terminal gear to unbaited artificial lures.

[e] In addition to the special regulations, a catch-and-release area was created on the Upper Chena River (river km 140.8 to 123.2).

[f] The daily bag and possession limits were reduced from five fish to two fish in 1990.

[g] During 1991, the Chena River and its tributaries were closed to possession of Arctic grayling from 1 July through 31 December.

[h] During 1992 and 1993, the Chena River and its tributaries were closed to possession of Arctic grayling from 1 January through 31 December.

[i] Averages are for 1979 through 1993 only.

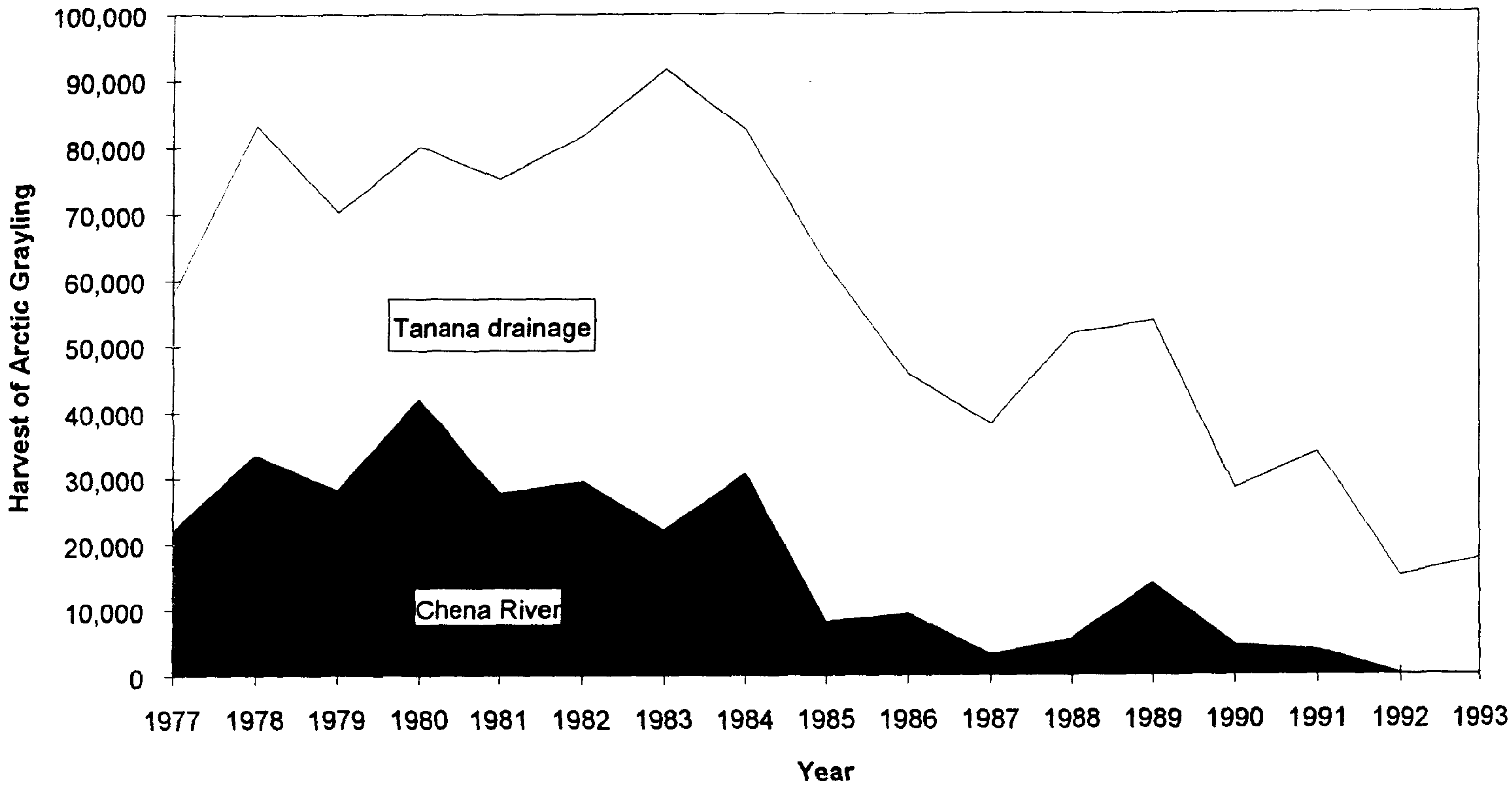

Figure 1.-Annual harvests of Arctic grayling in the Chena River and in the entire Tanana River drainage, 1977-1993 (taken from Mills 1979-1994).

3. restriction of terminal gear to unbaited artificial lures.

These regulations were made permanent in the summer of 1987. During the winter of 1987, fishery managers presented stock status and regulatory concerns to the Alaska Board of Fisheries (Clark 1987). The emergency regulations imposed in spring of 1987 were adopted and amended. The new permanent regulations were:

1. catch-and-release fishing from 1 April to the first Saturday in June;
2. a 12 inch (305 mm) minimum total length limit from the first Saturday in June until 31 March;
3. restriction of terminal gear to unbaited artificial lures only throughout the Chena River, and bait fishing allowed downstream of the Moose Creek Dam with hooks having a gap larger than 0.75 inch (19 mm);
4. catch-and-release fishing year around from river kilometer 140.8 downstream to river kilometer 123.2; and,
5. reduce the possession limit from 10 to 5 fish (Tanana River drainage-wide regulation).

The regulations adopted by the Board of Fisheries in winter of 1987 were the first changes in Arctic grayling management since 1975, when the daily bag limit was decreased from 10 to 5 fish. Evaluation of the effects of new regulations on the Arctic grayling stock and recreational anglers began in 1987.

In 1990, continued concern for the Arctic grayling stock in the Chena River prompted the Board of Fisheries to implement a daily bag limit of two fish, riverwide, and single hook regulations upstream of the Moose Creek Dam. On 1 July 1991, fishery managers invoked Emergency Order authority to reduce the daily bag limit to 0 fish in the entire Chena River drainage. This Emergency Order remained in effect through 1994. In 1994, the Board of Fisheries passed a regulation to keep the daily bag limit at 0 fish through 1997.

Concomitant with a daily bag limit of 0 fish, fishery managers began a rehabilitation program for Arctic grayling in the Chena River. The rehabilitation program had two main parts: regulation changes to ensure adequate protection of the stock, and a program of supplementation of natural production with releases of hatchery and pond-reared Arctic grayling. Beginning in spring of 1992, the first lot of fertilized eggs were taken from the Chena River stock for use in supplementing natural production. During 1993 a second lot of fertilized eggs were taken and 64,936 97-g fish (1992 brood year) stocked into the Chena River from Clear Hatchery. During 1994, 61,435 94-g fish (1993 brood year) were stocked. Stock assessment of Arctic grayling in 1994 focused on separation of hatchery fish from wild fish for estimation of abundance and size composition, and estimation of annual survival of hatchery-reared fish.

OBJECTIVES FOR STOCK ASSESSMENT

In order to accurately and precisely describe the stock status of Arctic grayling in the Chena River, the following objectives were addressed in 1994:

1. to estimate the abundance of Arctic grayling $\geq$ 150 mm FL in the lower 152 km of the Chena River;

2. to estimate the proportion of Arctic grayling (≥ 150 mm FL) in each of four groups (wild fish, age 1 hatchery releases, age 2 hatchery releases, and age 2 pond-reared releases) in the lower 152 km of the Chena River;
3. to estimate the age composition of wild Arctic grayling in the lower 152 km of the Chena River; and,
4. to estimate the size composition of Arctic grayling (wild fish, age 1 hatchery releases, age 2 hatchery releases, and age 2 pond-reared releases) in the lower 152 km of the Chena River.

In addition to these primary objectives, recruitment of new fish to the stock, the annual survival rate of the stock, and survival of age 1 and age 2 hatchery releases were estimated.

METHODS

AGE 1 HATCHERY-REARED FISH

As part of the rehabilitation of the Chena River stock, age 1 hatchery-reared Arctic grayling were released in six locations (Figure 2) along the Chena River during 7 through 30 June 1994. Prior to release (1 through 6 March 1994) each fish was marked by complete removal of the right ventral fin. Again prior to release (19 May 1994), a sample of 304 fish was taken with each fish checked for a recognizable fin clip, a sample of scales taken from 120 of these sampled fish, and fork length measured to the nearest 1 mm. For release, fish were transported in four aerated holding tanks mounted to a flat-bed truck. Number of fish to be released was estimated at the hatchery by weighing lots of fish as they were loaded into the holding tanks. The average weight of a subsample of fish was used to convert total weight of fish loaded into number of fish. Water in the transport tanks was treated with 8 g of methane sulfonate (MS-222) per tank. Each tank was aerated with oxygen to supersaturation during transport. Upon arrival at the release location, aeration was halted in each tank until oxygen concentration declined to between 90% and 100% saturation. Fish were then released into areas of backwater or eddy in the river. Water temperature of the holding tanks and the river were taken during release. Immediate mortalities or problems with transport were noted.

SAMPLING GEAR AND TECHNIQUES

During 1994, all sampling was performed with pulsed-DC (direct current) electrofishing systems mounted on 6.1-m-long river boats as previously described by Lorenz (1984). Input voltage (240 VAC) was provided by a 3,500 or 3,800 W single-phase gas powered generator. A variable voltage pulsator (Coffelt Manufacturing Model VVP-15) was used to generate output current. Anodes were constructed of 16.0 mm diameter and 1.5 m long twisted steel cable. Four anodes were attached to the front of a 3-m-long "T-boom" attached to a platform at the bow of the river boat. The aluminum hull of the river boat was used as the cathode. Output voltages during sampling varied from 200 to 300 VDC. Amperage varied from 2.5 to 4.0 A. Duty cycle and pulse rate were held constant at 50% and 60 Hz, respectively. These operating characteristics were presumed to minimally affect Arctic grayling survival during mark-recapture experiments. Water conductivity was 180 μS (at 25°C) during electrofishing.

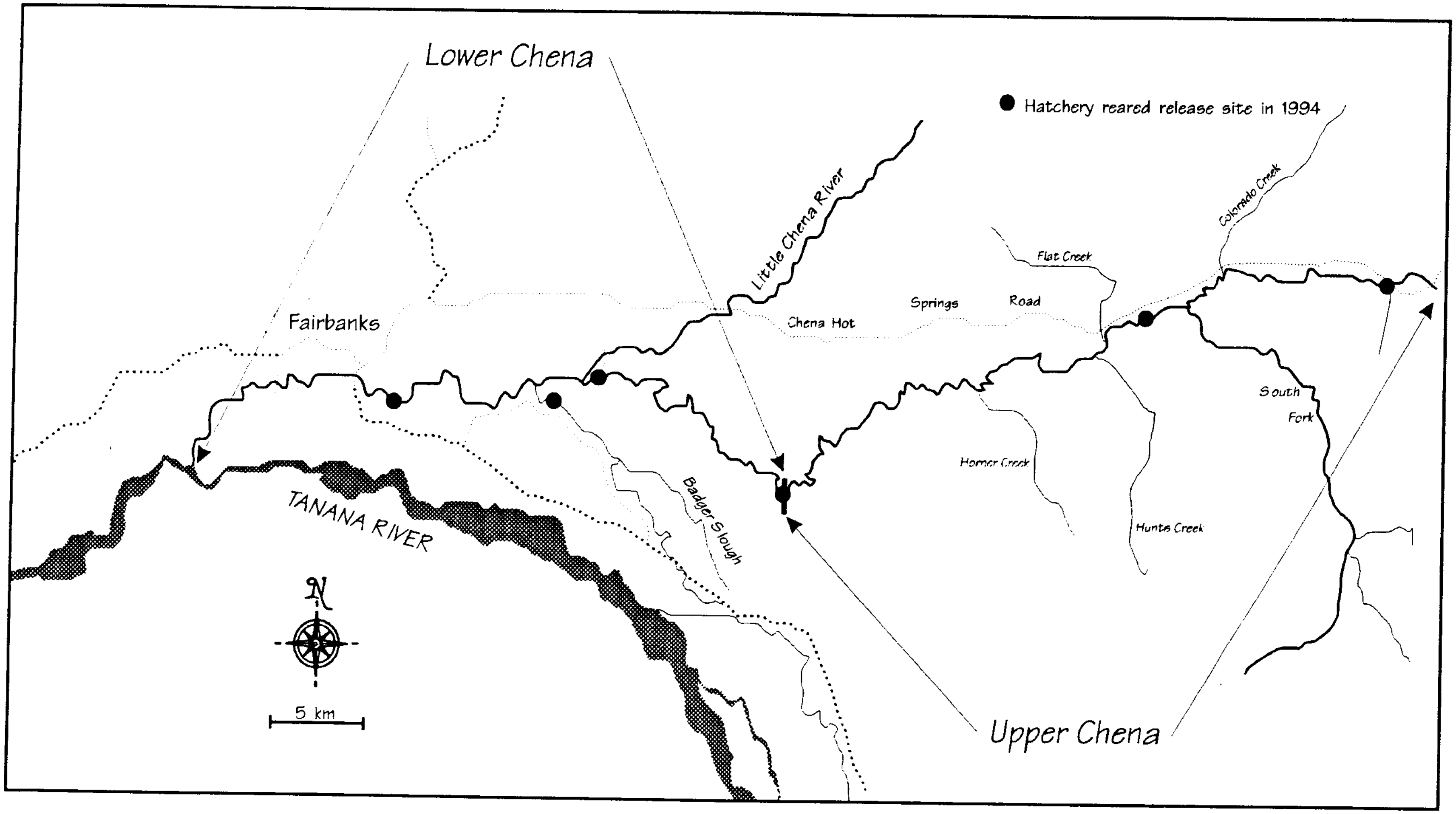

Figure 2.-Stock assessment sections in 1994 and hatchery-reared release sites in 1994 along the lower 152 km of the Chena River drainage.

Sampling was conducted along the banks of the Chena River. Two electrofishing boats were each directed downstream along one bank, capturing all Arctic grayling seen, when possible. Captured Arctic grayling were held in an aerated holding tub to reduce capture related stress. The two river sections were sampled no more than once per day to prevent changes in capture probabilities of marked fish (Cross and Stott 1975). Each Arctic grayling was measured to the nearest 1 mm FL. During the second event of the mark-recapture experiments, a sample of scales was taken from an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin of each wild Arctic grayling. During the same event, a sample of scales was taken from the same area of 120 age 1 and all age 2 hatchery-reared enhancement fish. Arctic grayling ≥ 150 mm FL were marked with an upper caudal punch for the Lower Chena section and a lower caudal punch for the Upper Chena section. All enhancement fish (hatchery and pond-reared releases) were marked with a complete fin clip (complete left or right ventral for hatchery and adipose for pond-reared releases) prior to release. If any captured Arctic grayling exhibited signs of injury or imminent mortality, they were immediately dispatched.

ESTIMATION OF ABUNDANCE

The abundance of Arctic grayling ≤ 150 mm FL was estimated by mark-recapture techniques in the lower 152 km of the mainstem Chena River (Figure 3). Two sections of the Chena River were delineated for separate estimation experiments. Delineation of the Chena River was necessary because of differences in capture probability of Arctic grayling in different sections of river (Figure 4). Based on differences in capture probability from downstream to upstream areas of the Chena River, the lower 152 km of the Chena River is divided into Lower and Upper sections for estimating abundance and age composition. Downstream from the Moose Creek Dam complex to the mouth of the Chena River was designated the Lower Chena section (72 km long; Figure 2). Upstream from the dam to the first bridge on the Chena Hot Springs Road (kilometer 62.4) was designated the Upper Chena section (80 km long; Figure 2). Population abundance estimates pertain only to these two sections of the Chena River, excluding Badger Slough, the Little Chena River, and the South Fork of the Chena River.

Abundance of Arctic grayling ≥ 150 mm FL was estimated with the modified Petersen estimator of Bailey (1951, 1952). Two electrofishing boats were used to mark Arctic grayling along both banks of the Lower (72 km long) and Upper Chena (80 km long) sections. Marking of fish in each section required four days, sampling four areas within a section. After a hiatus of seven days the two electrofishing boats were used in the same way to capture marked and unmarked Arctic grayling. The Lower Chena experiment was conducted during the first two weeks of July and the Upper Chena experiment was conducted during the last two weeks of July.

The assumptions necessary for accurate estimation of abundance in a closed population are (from Seber 1982):

1. the population is closed (no change in the number of Arctic grayling in the population during the estimation experiment);
2. all Arctic grayling have the same probability of capture in the first sample <u>or</u> in the second sample, <u>or</u> marked and unmarked Arctic grayling mix completely between the first and second samples;

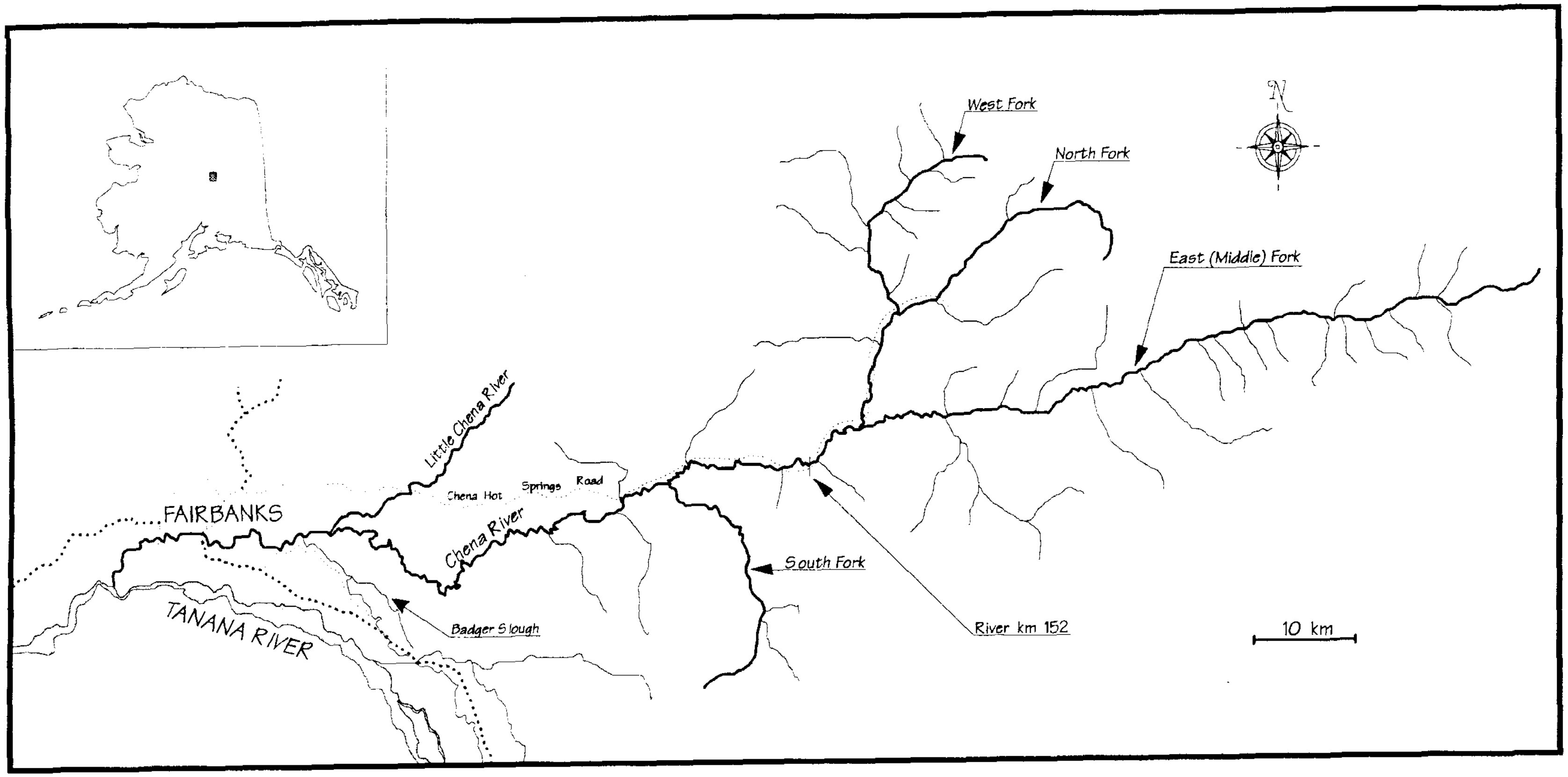

Figure 3. The Chena River drainage.

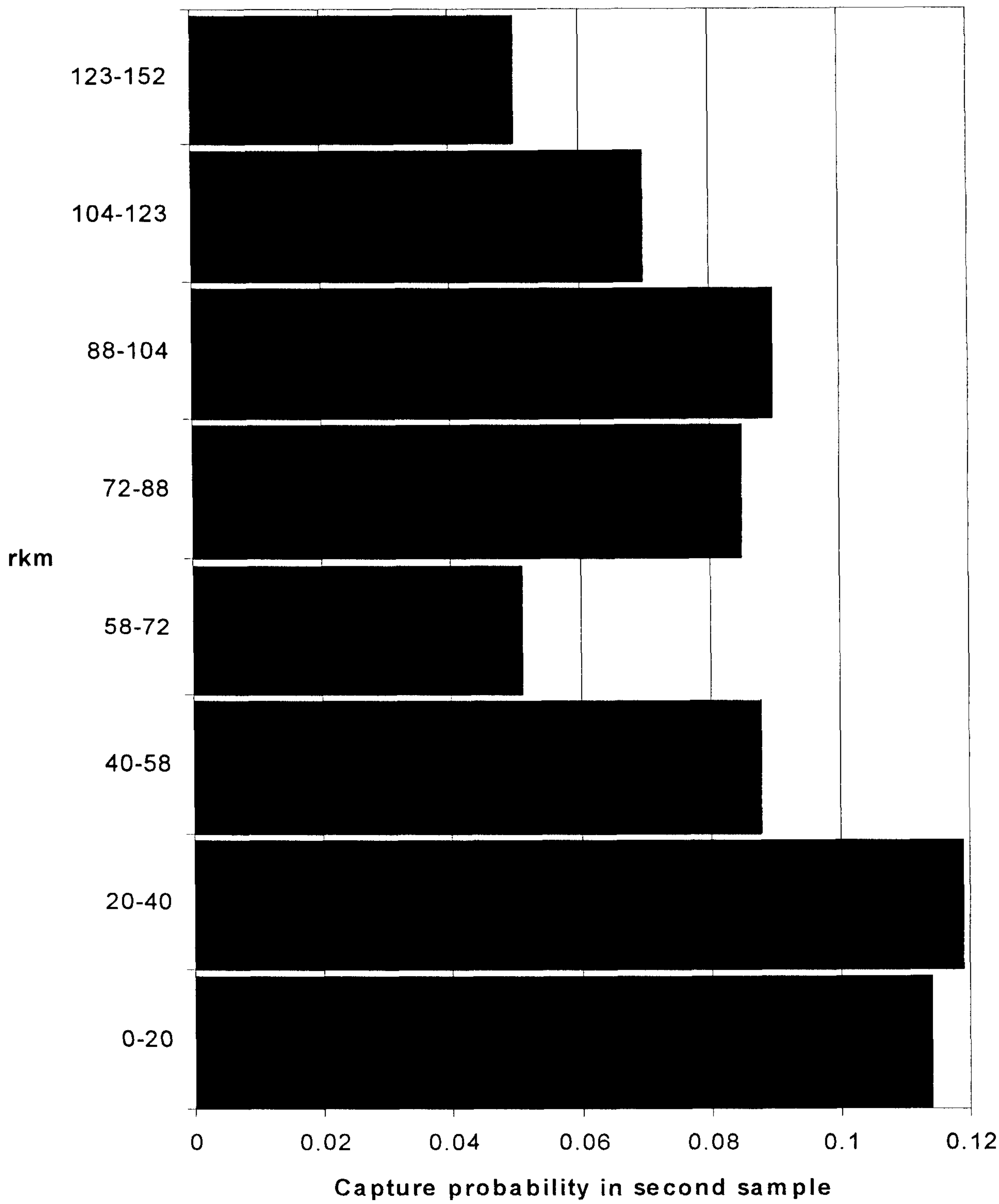

Figure 4.-Recapture-to-catch ratios of wild and age 2 hatchery-reared Arctic grayling (≥ 150 mm FL) in eight reaches of the Chena River in 1994 (rkm is river kilometer).

3. marking of Arctic grayling does not affect their probability of capture in the second sample;
4. Arctic grayling do not lose their mark between sampling events; and,
5. all marked Arctic grayling are reported when recovered in the second sample.

Testing of Assumptions:

Assumption 1 was implicitly assumed because of the large size of the sections (72 and 80 km) and short duration of the experiments (two weeks). A large section of river reduced the probability of fish leaving the section between sampling events. The short duration reduced the likelihood that mortality or recruitment due to growth would occur between sampling events. Assumptions 4 and 5 were assumed to be valid because of double marking of tagged Arctic grayling and rigorous examination of all captured Arctic grayling.

Assumptions 2 and 3 were tested directly in three ways. First, changes in capture probability may have occurred within a section of river. These potential changes were investigated by dividing each river section into four areas, each area encompassing the distance traveled during a single day of electrofishing. To determine if capture probability did change between areas, the recapture-to-catch ratios of each area were compared using a chi-squared contingency table. The four rows of the table were the different areas and the two columns of the table were the number of recaptures in the area and the number of unmarked fish examined during the second event in the same area. If the recapture-to-catch ratios were significantly different ($\alpha = 0.05$), the data were stratified into areas and separate abundance estimates calculated for each area.

Secondly, capture probability may differ by size of fish. Electrofishing is notorious for selecting for the largest fish in a population (Reynolds 1983), so that larger fish have a higher capture probability than smaller fish. Two Kolmogorov-Smirnov (K-S) statistical tests were used to determine if capture probability differs by size of fish. The first KS test compared the length frequency distribution of recaptured Arctic grayling with those captured during the marking event. The second K-S test compared the length frequency distribution of Arctic grayling captured during the marking event with those captured in the recapture event (see Bernard and Hansen 1992 for a description of tests). The first K-S test was used to determine if capture probability varied by size of fish. If significantly different, the size at stratification was determined by performing a series of chi-squared tests at differing sizes (using two size strata). The size at stratification that produced the largest chisquared value (the greatest difference in capture probability) was used to stratify the data for separate abundance estimation. The second K-S test was used to determine if age and size data needed to be corrected for changes in capture probability (see Estimation of Age and Size Composition below).

Lastly, capture probability may differ among wild and hatchery-reared fish. The method chosen to alleviate this potential bias was to separate the mark-recapture data into two groups. One group was wild and age 2 hatchery-reared fish and the second group was newly released age 1 hatchery-reared fish and perform the aforementioned tests on each group separately.

Calculation of Abundance:

After mark-recapture data were possibly stratified into areas and/or size classes with equal capture probabilities, estimated abundance was calculated from numbers of Arctic grayling marked, examined for marks, and recaptured (Bailey 1951; Seber 1982):

$$\hat{N}_i = \frac{n_1(n_2+1)}{m_2+1} \quad (1)$$

where: n_1 = the number of Arctic grayling marked and released alive during the first sample in stratum *i*; n_2 = the number of Arctic grayling examined for marks during the second sample in stratum *i*; m_2 = the number of Arctic grayling recaptured during the second sample in stratum *i*; and, $\hat{N}_i$ = estimated abundance of Arctic grayling during the first sample in stratum *i*.

Variance was estimated by (Seber 1982):

$$\hat{V}[\hat{N}_i] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \quad (2)$$

Bailey's (1951, 1952) modification was used instead of the more familiar modification by Chapman (1951) because of the sampling design used on each river section. Seber (1982) found that if the assumption of a random sample for the second sample was false and a systematic sample was taken (for example, a systematic sample of both banks of the Chena River), then the binomial model of Bailey (1951, 1952) is most appropriate. The binomial model will hold in this situation when:

1. there is uniform mixing of marked and unmarked fish; and,
2. all fish, whether marked or unmarked, have the same probability of capture.

The sample design used in each river section does not allow for thorough mixing of fish marked at the uppermost reaches with those marked in the downstream reaches, although local mixing of marked and unmarked fish probably occurs.

Estimated abundance and variance of wild and hatchery fish in the lower 152 km of the Chena River was calculated as the sum of all strata (either areas, sizes, or both) from the Lower and Upper Chena sections:

$$\hat{N} = \sum_{i=1}^{s} \hat{N}_i \text{, and} \quad (3)$$

$$\hat{V}[\hat{N}] = \sum_{i=1}^{s} \hat{V}[\hat{N}_i]. \quad (4)$$

where: s = the number of strata needed to alleviate bias due to changes in capture probability.

In 1994 there were four strata (s = 4) for wild and age 2 hatchery-reared fish: two size strata in the Lower Chena section and two size strata in the Upper Chena section. Abundance of age 2 hatchery-reared fish was estimated by apportioning the abundance of wild and age 2 hatchery-reared fish by the proportion of age 2 hatchery-reared fish in catches. First, the proportion of age 2 hatchery-reared fish in catches of wild and age 2 hatchery-reared fish (excluding age 1 hatchery-reared fish) was estimated:

$$\hat{r}_{AGE2} = \frac{n_{AGE2}}{n_{WILD+AGE2}} \quad (5)$$

where: $\hat{r}_{AGE2}$ = the proportion of age 2 hatchery-reared fish in the catch; n_{AGE2} = the number of age 2 hatchery-reared fish in the catch (n_2 from equation 1); and, $n_{WILD+AGE2}$ = the number of wild and age 2 hatchery-reared fish in the catch.

Variance of this proportion was estimated as the variance of a binomial. Then the abundance of age 2 hatchery-reared fish was estimated from the mark-recapture estimate of abundance and the estimated proportion:

$$\hat{N}_{AGE2} = \hat{r}_{AGE2}\hat{N}_{WILD+AGE2} \tag{6}$$

where: $\hat{N}_{AGE2}$ = the abundance of age 2 hatchery-reared fish; and, $\hat{N}_{WILD+AGE2}$ = the abundance of wild and age 2 hatchery-reared fish.

Variance of equation 6 was estimated with the formula for the variance of the product of two independent variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_{AGE2}\right] = \hat{r}^2_{AGE2}\hat{V}\left[\hat{N}_{WILD+AGE2}\right] + \hat{N}^2_{WILD+AGE2}\hat{V}\left[\hat{r}_{AGE2}\right] - \hat{V}\left[\hat{N}_{WILD+AGE2}\right]\hat{V}\left[\hat{r}_{AGE2}\right] \tag{7}$$

Estimates of age 2 hatchery-reared fish were then summed by river section as in equations 3 and 4. There were three strata (s = 3) for age 1 hatchery-reared fish: two area strata in the Lower Chena section and one stratum in the Upper Chena section.

ESTIMATION OF AGE AND SIZE COMPOSITION

Collections of wild Arctic grayling for age-length samples were conducted in conjunction with abundance estimation experiments. Age composition was described with proportions of the stock contained in each age class from 2 through 12 years (third through thirteenth summers, respectively). Size composition of Arctic grayling in each of the river sections was described with the incremental Relative Stock Density (RSD) indices of Gabelhouse (1984). The RSD categories are: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and, "trophy" (greater than 559 mm FL). Incremental size composition was also estimated for each 10 mm increment of fork length from 150 mm to 450 mm. Incremental size composition was also used to describe the sizes of hatchery-reared fish sampled in the Chena River.

From tests of assumptions 2 and 3 for estimation of abundance, significant differences in capture probability by area and/or size of fish were found. Differences in capture probability may also bias estimates of age and size compositions. If significant changes in capture probability were detected, age and size data were adjusted for these differences so that the age and size composition of Arctic grayling in the lower 152 km of the Chena River could be estimated. First, the proportions of fish by age class or size category were estimated for each stratum used in estimation of abundance:

$$\hat{p}_{ik} = \frac{n_{ik}}{n_i} \tag{8}$$

where: $\hat{p}_{ik}$ = the proportion of age or size category *k* fish sampled in stratum *i*; n_{ik} = the number of age or size category *k* fish sampled in stratum *i*; and, n_i = the number of fish sampled in stratum *i*.

Variance of this proportion was estimated as the variance of a binomial. Next the abundance of each age class or size category was estimated from the proportions and abundance in each stratum:

$$\hat{N}_{ik} = \hat{p}_{ik}\hat{N}_i \tag{9}$$

where: $\hat{N}_{ik}$ = the abundance of age or size category *k* fish in stratum *i*.

Variance of each abundance at age or size was estimated with the formula for the variance of the product of two independent variables (as in equation 7). After calculating abundances at age or size in each stratum, the overall proportions were estimated by:

$$\hat{\bar{p}}_k = \sum_{i=1}^{s}\frac{\hat{N}_i}{\hat{N}}\hat{p}_{ik} \tag{10}$$

where: $\hat{\bar{p}}_k$ = the average weighted proportion of Arctic grayling in the lower 152 km of the Chena River that were age or size *k*; $\hat{N}_i$ = the abundance of Arctic grayling in stratum i; $\hat{N}$ = summed abundance of all strata (from equation 3); and, $\hat{p}_{ik}$ = the proportion of Arctic grayling in stratum *i* that were age or size *k*.

Variance of the proportions were approximated with the delta method (see Seber 1982):

$$\hat{V}\left[\hat{\bar{p}}_k\right] \approx \sum_{i=1}^{s}\frac{\left(\hat{p}_{ik} - \hat{\bar{p}}_k\right)^2 \hat{V}\left[\hat{N}_i\right]}{\hat{N}^2} + \sum_{i=1}^{s}\left(\frac{\hat{N}_i}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{ik}\right] \tag{11}$$

These average weighted proportions and variances by age and size were used as estimates of age and size compositions in the lower 152 km of the Chena River.

ESTIMATION OF PROPORTION OF HATCHERY-REARED FISH

The proportion of age 1 hatchery-reared fish in the lower 152 km of the Chena River was estimated as the quotient of the abundance of age 1 hatchery-reared fish and total abundance (wild plus all enhancement cohorts):

$$\hat{p}_{AGE1} = \frac{\hat{N}_{AGE1}}{\hat{N}_{AGE1} + \hat{N}_{WILD} + \hat{N}_{AGE2}} = \frac{\hat{N}_{AGE1}}{\hat{N}_{ALL}} \tag{12}$$

where: $\hat{p}_{AGE1}$ = proportion of the population that was from age 1 hatchery-reared releases in the lower 152 km of the Chena River; and, $\hat{N}_x$ = abundance of age 1 (AGE1) hatchery-reared releases, or wild fish (WILD), or age 2 hatchery-reared releases (AGE2) in the lower 152 km of the Chena River.

Variance of the proportion was approximated with the formula for the quotient of two dependent variables (Bernard 1983):

$$\hat{V}[\hat{p}_{AGE1}] \approx \hat{p}_{AGE1}^2 \cdot \left(\frac{\hat{V}[\hat{N}_{AGE1}]}{\hat{N}_{AGE1}^2} + \frac{\hat{V}[\hat{N}_{ALL}]}{\hat{N}_{ALL}^2} - \frac{2\hat{V}[\hat{N}_{AGE1}]}{\hat{N}_{AGE1}\hat{N}_{ALL}} \right) \tag{13}$$

Equations 12 and 13 were also used to calculate the proportion of age 2 hatchery-reared fish in the population.

To examine changes in the proportion of hatchery-reared releases from downstream to upstream over the lower 152 km of the Chena River, catches of wild and hatchery-reared fish were recorded for each electrofishing run during the mark-recapture experiment. Capture probabilities of wild and hatchery-reared fish were compared with chi-squared contingency tables as detailed above (Testing of Assumptions). If capture probability of wild and hatchery-reared fish were similar for a particular area within a section, then the catches were used as an estimate of the proportion of hatchery-reared fish by electrofishing for that particular area. If capture probabilities differed for a particular area then the abundances of wild and hatchery-reared fish in that area were used to adjust the proportions in each run. First, it was assumed that capture probabilities of hatchery-reared fish were similar between all electrofishing runs within an area. This assumption applied to all wild fish in an area as well. The abundance of hatchery-reared fish in a particular electrofishing run was estimated by first estimating the proportion of the total catch of hatchery-reared fish in that area that were caught in that particular run:

$$\hat{p}_{E_{im}} = \frac{e_{im}}{e_i}, \text{ or } \hat{p}_{W_{im}} = \frac{w_{im}}{w_i} \tag{14}$$

where: $\hat{p}_{E_{im}}$ = the proportion of hatchery-reared fish caught in area stratum *i* that were in electrofishing run *m*; e_{im} = the number of hatchery-reared fish caught in electrofishing run *m* of area stratum *i*; e_i = the number of hatchery-reared fish caught in area stratum *i*; $\hat{p}_{W_{im}}$ = the proportion of wild fish caught in area stratum *i* that were in electrofishing run *m*; w_{im} = the number of wild fish caught in area stratum *i* that were in electrofishing run *m*; and, w_i = the number of wild fish caught in area stratum *i*.

Variances of equation 14 were estimated with the formula for the variance of a binomial. These proportions were also separately estimated for wild fish in each run.

Next, the abundances of hatchery-reared and wild fish were estimated for each run (showing the equation for hatchery-reared fish):

$$\hat{E}_{im} = \hat{p}_{E_{im}} \hat{E}_i \tag{15}$$

where: $\hat{E}_{im}$ =the abundance of hatchery-reared fish in run *m* of area stratum *i* and, $\hat{E}_i$ = the abundance of hatchery-reared fish in area stratum *i*.

Variance of equation 15 was estimated with the formula for the variance of the product of two independent variables (Goodman 1960). The proportion of hatchery-reared fish in the run was then estimated by dividing the abundance of hatchery-reared fish in the run by the total abundance in the run:

$$\hat{p}'_{E_{im}} = \frac{\hat{E}_{im}}{\left(\hat{E}_{im} + \hat{W}_{im}\right)} \tag{16}$$

Variance of equation 16 was estimated with the approximate formula for the variance of the quotient of two dependent variables (as in equation 13). These calculations were performed in all areas where the recapture-to-catch ratios of wild and hatchery-reared fish were dissimilar. If recapture-to-catch ratios were similar, the catches of wild and hatchery-reared fish in each run were used to estimate the proportion of hatchery-reared fish in the run:

$$\hat{p}'_{E_{im}} = \frac{e_{im}}{\left(e_{im} + w_{im}\right)} \tag{17}$$

Variance of equation 17 was estimated with the formula for the variance of a binomial.

ESTIMATION OF SURVIVAL AND RECRUITMENT

As of 1994, nine years of population abundance and age composition estimates had been completed for the lower 152 km of the Chena River. Using data from 1986 through 1993, Clark (1994) reported on survival rates and recruitment for 1986 through 1992. Survival rate and recruitment for 1993 was calculated in the same manner.

Annual recruitment was defined as the number of age 3 Arctic grayling added to the population between year *t* and year *t+1*, and alive in year *t+1*. Estimates of recruitment were simply the estimates of abundance of age 3 Arctic grayling in 1993 and 1994. Variance of the recruitment estimates were the variance of abundance at age 3 for these same years.

With recruitment and abundance at age estimates in years *t* and *t+1*, the estimate of survival rate between year *t* and year *t+1* was:

$$\hat{S}_{t,t+1} = \frac{\hat{N}'_{t+1}}{\hat{N}_t} \tag{18}$$

where: $\hat{N}'_{t+1} = \sum_{k=4}^{12} \hat{N}_{t+1,k}$ = the abundance of age *k* and older Arctic grayling in year *t*+1; and,

$\hat{N}_t = \sum_{k=3}^{12} \hat{N}_{t,k}$ = the abundance of age *k* and older Arctic grayling in year *t*.

The variance of annual survival was approximated as the variance of a quotient of two independent variables with the delta method (Seber 1982):

$$\hat{V}\left[\hat{S}\right] \approx \left[\frac{\hat{N}'_{t+1}}{\hat{N}_t}\right]^2 \left[\frac{\hat{V}\left[\hat{N}'_{t+1}\right]}{\hat{N}'^2_{t+1}} + \frac{\hat{V}\left[\hat{N}_t\right]}{\hat{N}^2_t}\right] \tag{19}$$

where: $\hat{V}\left[\hat{N}'_{t+1}\right] = \sum_{k=4}^{12} \hat{V}\left[\hat{N}'_{t+1,k}\right]$;and, $\hat{V}\left[\hat{N}_{t}\right] = \sum_{k=3}^{12} \hat{V}\left[\hat{N}_{t,k}\right]$.

HISTORIC DATA SUMMARY

Data collected from the Chena River (1955 to 1994) were summarized in Appendix A. Creel survey estimates, population abundance estimates, length at age estimates, age composition estimates, size composition estimates, and a model of Arctic grayling growth were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1959 to the present (Appendix A). When possible, estimates of precision were reported with point estimates. Precision was reported as either standard error or 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Length frequency was generally reported in the literature as numbers sampled per 10 mm length increment. The length frequency distributions were converted into the RSD categories of Gabelhouse (1984) for comparison with data collected from 1986 to 1994. In addition to the aforementioned reports in Appendix A, Arctic grayling migration studies were summarized in a report by Tack (1980). Reports concerning Arctic grayling research from 1952-1980 were compiled by Armstrong (1982). Armstrong et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985. In addition, Clark (1992b) estimated age and size at maturity for the Chena River stock in 1991 and 1992, and Clark (1993) estimated interannual intrastream movements of tagged fish for 1987 through 1992. A list of electronic data files used in analyses for 1994 are found in Appendix B.

RESULTS

AGE 1 HATCHERY-REARED FISH

Prior to release (19 May 1994) a sample of 304 age 1 hatchery-reared Arctic grayling were checked for the presence of an identifying fin clip (completely missing right ventral fin). Of these fish 303, or 99.7% of the sample (SE = 0.3%, normal approximation 95% C.I. = 99.0% to 100.0%), had an identifiable fin clip. Based on the percentage of identifiable fin clips in this sample, it was assumed that 99.7% of fish released into the Chena River had an identifiable fin clip. Average length of fish sampled was 197 mm FL (SE = 1 mm).

Between 7 and 30 June, 61,435 of the age 1 hatchery-reared fish were released at seven locations along the Chena River (Table 2). Average fork length of fish at release varied from 205 mm to 214 mm by release location and averaged 208 mm overall. Average weight of fish at release varied from 87 g to 101 g by release location and averaged 94 g overall. Water temperatures were not taken at every release location, but it was thought that river water temperature at the time of release ranged from 8.0°C to 14.0°C. Water temperature of the holding tanks at the time of release was 9.5°C.

LOWER CHENA SECTION

The Lower Chena experiment was performed during 5 through 14 July 1994. A total of 2,385 fish were marked, 3,130 fish were examined for marks, and 250 fish were recaptured during mark-recapture sampling. Twenty-nine immediate mortalities or serious injuries were recorded

Table 2.-Releases of hatchery-reared Arctic grayling into the Chena River during 7 through 30 June 1994.

Date	River km	Number released	Average length[a]	Average weight[b]
6/7	40	7,062	207	90
6/8	40	7,252	205	88
6/9	72	7,316	207	89
6/13	72	7,303	205	87
6/15	117	6,966	213	98
6/16	142	7,014	208	97
6/17	117	7,014	208	97
6/21	72	3,063	208	97
6/29	35[c]	1,257	214	101
6/30	22	7,188	214	101
Totals		61,435	208	94

[a] Average length is in millimeter fork length.
[b] Average weight is in gram.
[c] Fish were released into Badger Slough approximately 2 km upstream of the confluence with the Chena River (river kilometer 35).

for an overall injury rate of 0.9%. Mark-recapture data from wild and age 1 hatchery-reared fish were analyzed separately. Age 2 hatchery-reared fish were analyzed with wild fish.

Wild and Age 2 Hatchery-Reared Fish:

A total of 1,842 wild and age 2 hatchery-reared fish were marked, 2,011 fish were examined for marks, and 205 fish were recaptured during mark-recapture sampling. Recapture-to-catch ratios of wild and age 2 hatchery-reared fish varied significantly among four areas of the Lower Chena ($\chi^2 = 11.78$, df = 3, P $\approx$ 0.01; Figure 4). However, the summed estimate of abundance for the four areas (17,974 fish) did not differ markedly from the combined estimate of abundance (17,991 fish). Therefore, abundance, and age and size compositions were estimated for all four areas combined. Based on comparisons of length frequencies of marked fish with length frequencies of recaptured fish, there appeared to be marginal size selective sampling in the Lower Chena (D = 0.09, P $\approx$ 0.09; Figure 5A). Moreover, when length frequencies of marked and recaptured <u>wild</u> fish were compared there was a significant difference (D = 0.11, P $\approx$ 0.04; Figure 6A). The maximal chi-squared statistic occurred at a stratification of 150 to 220 mm FL for small fish and > 220 mm FL for large fish. Summing estimates of abundance from the two size strata (Table 3), abundance of wild and age 2 hatchery-reared fish in the Lower Chena was 18,805 fish (SE = 1,379 fish). The proportion of age 2 hatchery-reared fish in catches from the Lower Chena section differed by size ($\chi^2 = 11.07$, df = 1, P $\approx 8.80 \times 10^{-4}$; Table 4). There were 9.8% age 2 hatchery-reared fish in the small fish stratum and 14.7% age 2 hatchery-reared fish in the large fish stratum (Table 4). Abundance of wild fish was 16,535 fish (SE = 1,235 fish) and abundance of age 2 hatchery-reared fish was 2,270 fish (SE = 205 fish) or 12.1% of the combined abundance (Table 4).

There was a significant difference in the length frequencies of fish marked versus those examined for marks in the Lower Chena section (D = 0.08, P $\approx 9.68 \times 10^{-6}$; Figure 5B). Therefore the second sample (recapture event) was used to estimate age composition of wild fish and size compositions of wild and age 2 hatchery-reared fish. Age 4 and age 3 wild fish were most abundant in this section of river (Table 5). Ages 2 through 4 comprised 75% of abundance, with very few fish older than age 7. Similarly, stock size wild fish comprised 86% of abundance in the Lower Chena while only 1% of fish were of preferred size (Table 6). Size composition of age 2 hatchery fish was primarily (91.7%) comprised of fish between 200 and 260 mm FL.

Age 1 Hatchery-Reared Fish:

A total of 543 age 1 hatchery-reared fish were marked, 1,119 fish were examined for marks, and 45 were recaptured during mark-recapture sampling. Recapture-to-catch ratios did significantly differ among four areas of the Lower Chena ($\chi^2 = 14.10$, df = 3, P $\approx$ 0.01; Figure 7). However, three adjacent areas of these four had similar recapture-to-catch ratios and were combined ($\chi^2 = 3.15$, df = 2, P $\approx$ 0.21). Combination of areas resulted in two areas: river kilometer 0 to 58 and river kilometer 58 to 72. There was no significant difference in length frequencies of fish marked versus those recaptured (D = 0.07, P $\approx$ 0.99; Figure 8A), so that stratification of the data by size of fish was not necessary. The abundance of age 1 hatchery-reared fish, summed across areas, was 14,557 fish (SE = 2,840 fish; Table 7).

There was a significant difference in length frequencies of fish marked versus those examined for marks (D = 0.05, P $\approx$ 0.03; Figure 8B). Therefore the second sample (recapture event) was used

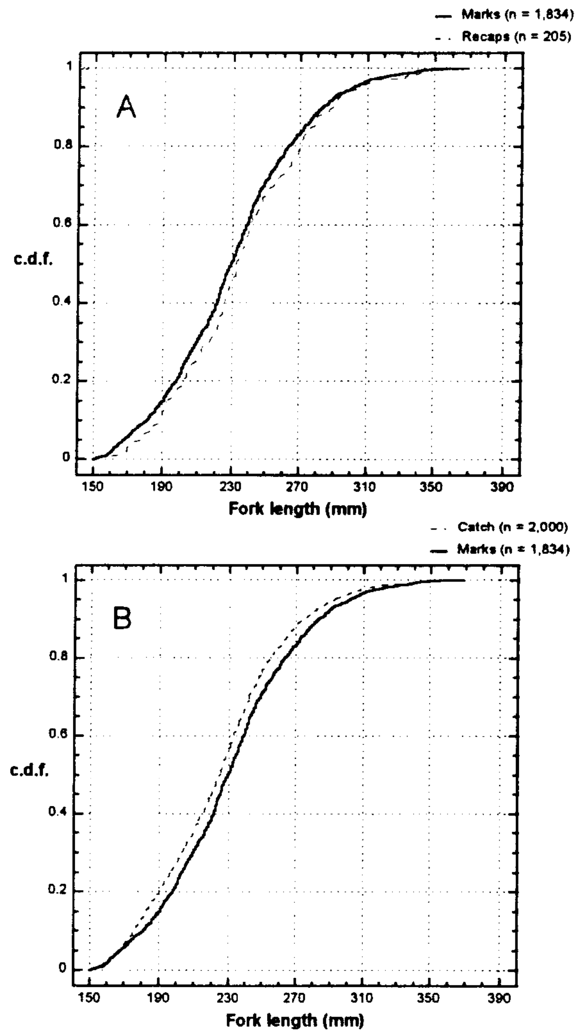

Figure 5.-Cumulative density functions (c.d.f.) of fork length of wild and age 2 hatchery-reared Arctic grayling marked, captured, and recaptured in the Lower Chena section of the Chena River, 5 through 14 July 1994.

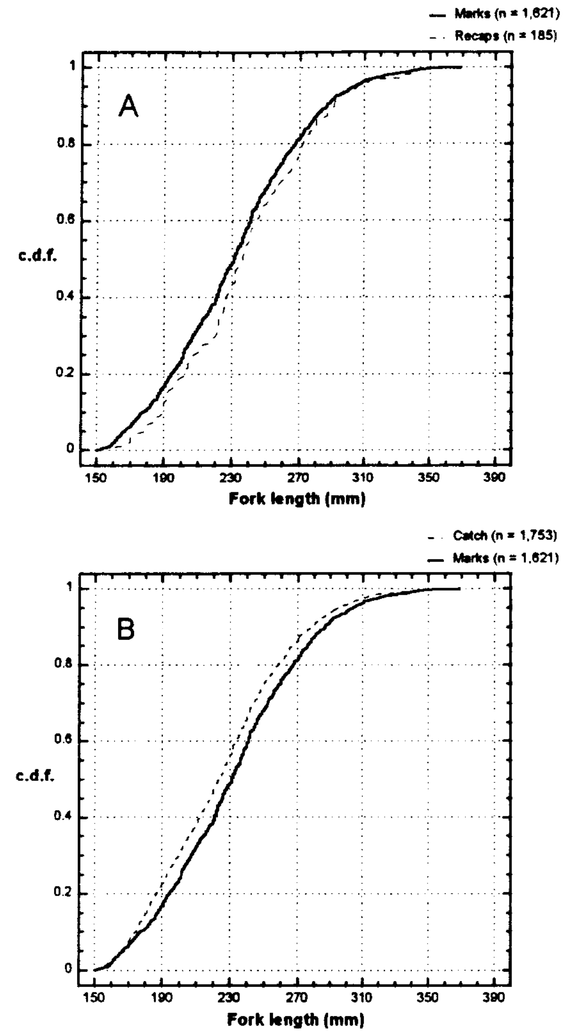

Figure 6.-Cumulative density functions (c.d.f.) of fork length of wild Arctic grayling marked, captured, and recaptured in the Lower Chena section of the Chena River, 5 through 14 July 1994.

Table 3.-Capture probabilities and estimated abundance in two size categories used for population estimation of wild and age-2 hatchery-reared Arctic grayling (≥150 mm FL) in the Lower Chena section of the Chena River, 5 through 14 July 1994.

	Size category		
	150 to 220 mm	>220 mm	Total
Mark(n_1)	728	1,114	1,842
Catch(n_2)	926	1,085	2,011
Recap(m_2)	65	140	205
m_2/n_1[a]	0.07	0.13	0.06
N[b]	10,225	8,580	18,805
SE[N][c]	1,204	672	1,379

[a] m_2/n_1 is the probability of capture.

[b] N is the estimated abundance in a size category.

[c] SE[N] is the standard error of N.

Table 4.-Estimates of apportioned abundance in two size categories used for population estimation of wild and age-1 hatchery-reared Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 5 through 14 July 1994.

	Size category		
	150-220 mm	≥221 mm	Total
Catch[a]			
AGE2	91	160	251
Wild	835	925	1,760
All	926	1,085	2,011
$p_{AGE}2$[b]	0.098	0.147	0.125
SE	0.010	0.011	0.007
Abundance[c]			
AGE2	1,005	1,265	2,270
SE	154	135	205
Wild	9,220	7,315	16,535
SE	1,090	580	1,235
All	10,225	8,580	18,805
SE	1,204	672	1,379

a Catches are of age-2 hatchery-reared fish (AGE2), wild fish (Wild), and wild plus age-2 hatchery-reared fish (All).

b p_{AGE2} is the proportion of age-2 hatchery-reared fish in the catches of All fish (AGE2 divided by All).

c Abundances are of age-2 hatchery-reared fish (AGE2), wild fish (Wild), and wild plus age-2 hatchery-reared fish (All).

Table 5.-Estimates of adjusted age composition and abundance by age class with standard errors for wild Arctic grayling (≥150 mm FL) captured by pulsed-DC electrofishing from the Lower Chena section of the Chena River, 11 through 14 July 1994.

	Age composition				Abundance		
Age	n[a]	p[b]	SE	CV	N[c]	SE	CV
2	240	0.20	0.02	7.9	3,299	359	10.9
3	328	0.27	0.02	7.0	4,463	455	10.2
4	432	0.28	0.01	5.2	4,613	419	9.1
5	168	0.10	0.01	9.5	1,672	202	12.1
6	132	0.08	0.01	11.0	1,278	170	13.3
7	73	0.04	0.01	13.6	704	109	15.5
8	29	0.02	<0.01	19.6	278	58	21.0
9	14	0.01	<0.01	27.2	134	38	28.1
10	9	0.01	<0.01	34.6	86	30	35.3
11	1	<0.01	<0.01	100.0	10	10	100.0
12	0	0	0	---	0	0	---
Total	1,426	1.00	---	---	16,535	1,235	7.5

[a] n = number of Arctic grayling sampled at age.

[b] p = estimated adjusted proportion of Arctic grayling at age in the population.

[c] N = estimated population abundance of Arctic grayling at age.

Table 6.-Summary of Relative Stock Density (RSD) indices of wild Arctic grayling (≥ 150 mm FL) captured in the Lower Chena section, 1994.

	RSD category[a]				
	S	Q	P	M	T
Number sampled	1,210	198	13	0	0
RSD	0.85	0.14	0.01	0.00	0.00
Adjusted RSD[b]	0.86	0.13	0.01	0.00	0.00
SE	0.01	0.01	<0.01	0.00	0.00
N	14,200	2,191	144	0	0
SE	1,085	271	43	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): stock(S) - 150 mm FL; quality(Q) - 270 mm FL; preferred(P) - 340 mm FL; memorable(M) - 450 mm FL; and, trophy(T) - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. Standard error of RSD is for the adjusted estimate.

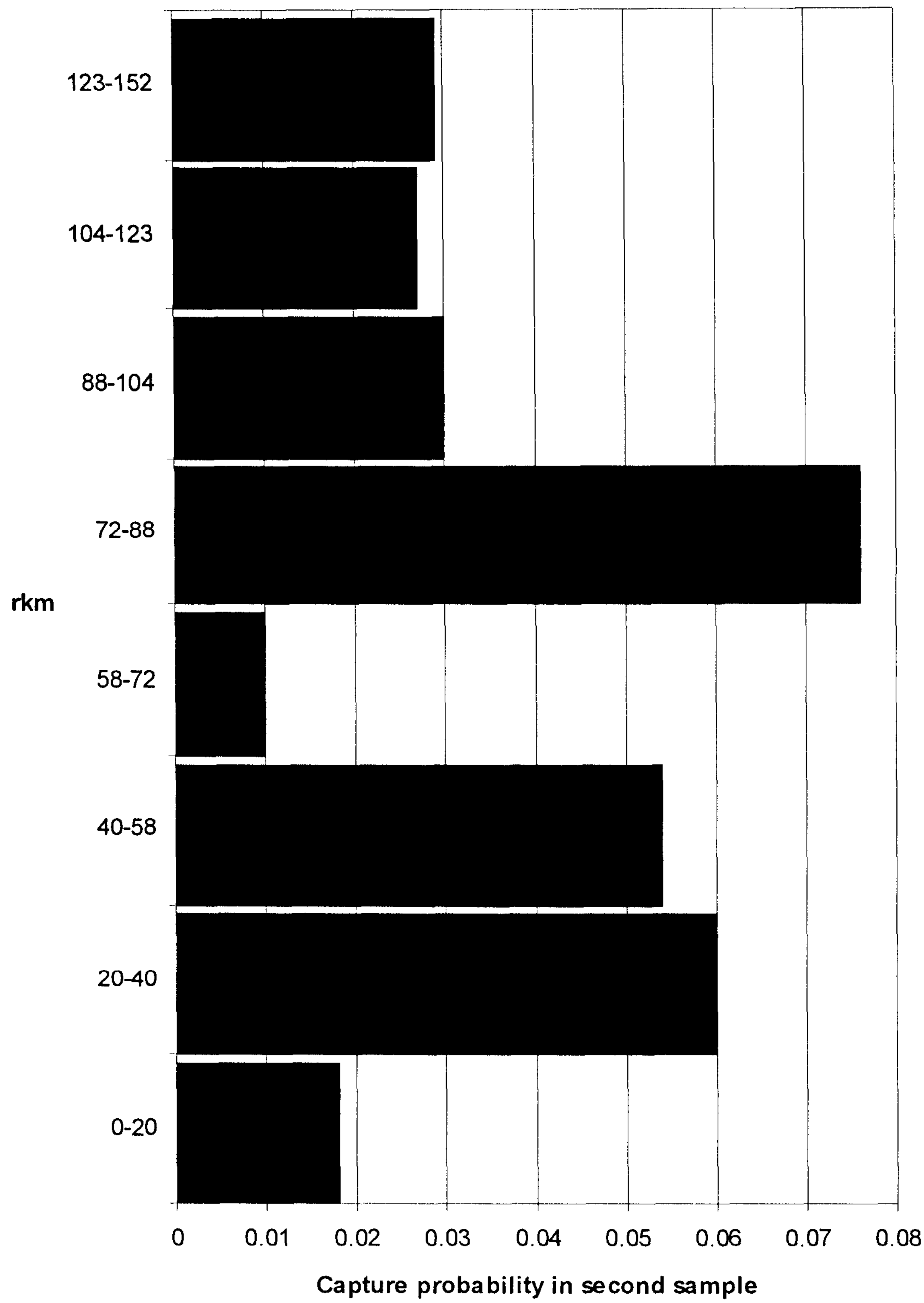

Figure 7.-Recapture-to-catch ratios of age 1 hatchery-reared Arctic grayling (≥ 150 mm FL) in eight reaches of the Chena River in 1994 (rkm is river kilometer).

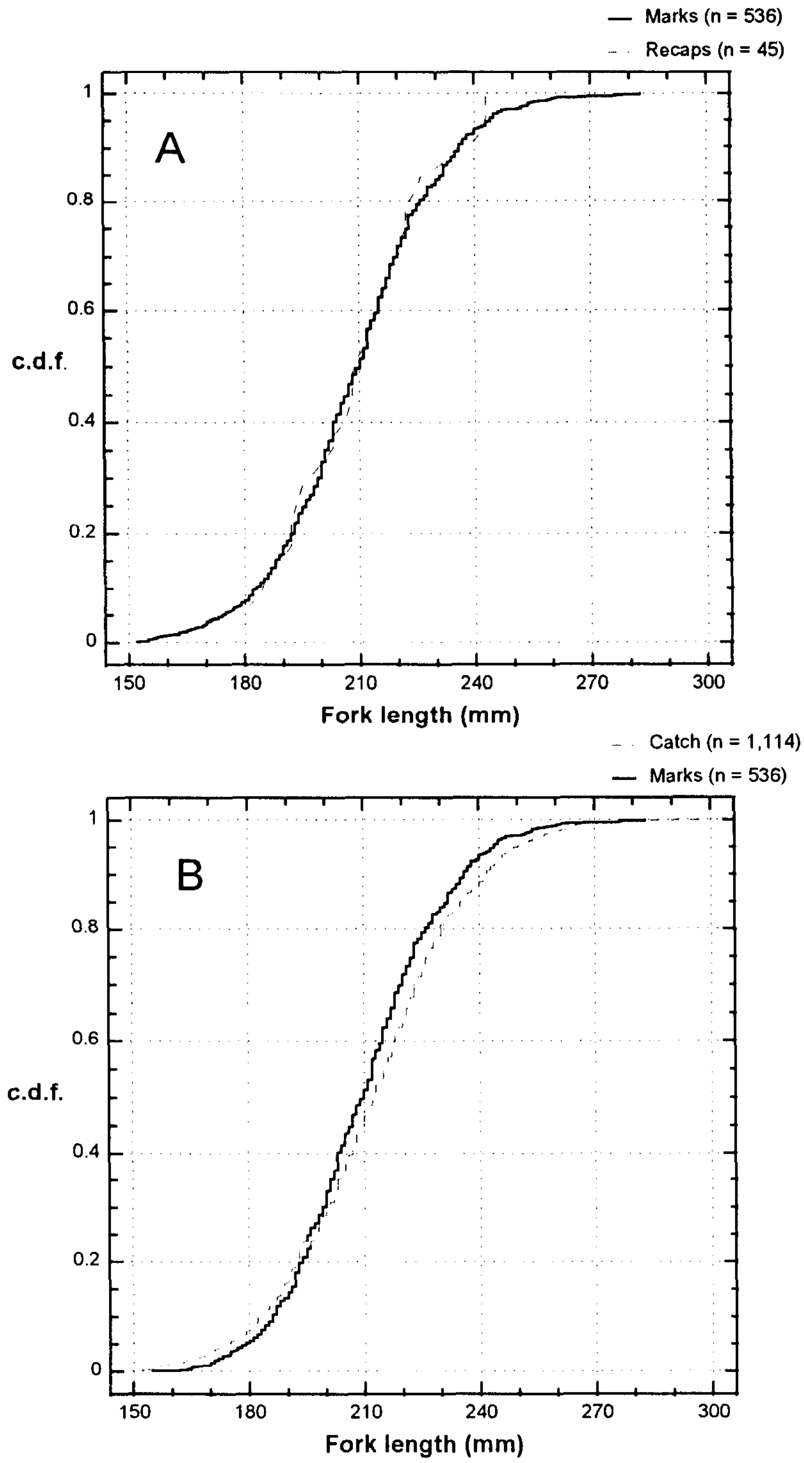

Figure 8.-Cumulative density functions (c.d.f.) of fork length of age 1 hatchery-reared Arctic grayling marked, captured, and recaptured in the Lower Chena section of the Chena River, 5 through 14 July 1994.

Table 7.-Capture probabilities and estimated abundance in two areas used for population estimation of age-1 hatchery-reared Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 5 through 14 July 1994.

	River kilometer		
	0 to 58	59 to 72	Total
Mark(n_1)	469	74	543
Catch(n_2)	813	306	1,119
Recap(m_2)	42	3	45
m_2/n_1[a]	0.09	0.04	0.08
N[b]	8,878	5,679	14,557
SE[N][c]	1,303	2,523	2,840

[a] m_2/n_1 is the probability of capture.

[b] N is the estimated abundance in an area.

[c] SE[N] is the standard error of N.

to estimate size composition. Most age 1 hatchery-reared fish were between 190 and 230 m FL (65.3%). Based on abundances of wild and hatchery-reared fish, the proportion of age 1 hatchery-reared fish in the Lower Chena was 0.44 (SE = 0.05) or 44%.

UPPER CHENA SECTION

The Upper Chena experiment was performed during 19 through 29 July 1994. A total of 2,882 fish were marked, 2,904 fish were examined for marks, and 163 fish were recaptured during mark-recapture sampling. Thirty-six immediate mortalities or serious injuries were recorded for an overall injury rate of 0.6%. Mark-recapture data from wild and age 1 hatchery-reared fish were analyzed separately. Age 2 hatchery-reared fish were analyzed with wild fish.

Wild and Age 2 Hatchery-Reared Fish:

A total of 1,807 wild and age 2 hatchery-reared fish were marked, 1,912 fish were examined for marks, and 125 were recaptured during mark-recapture sampling. Recapture-to-catch ratios did not significantly differ among four areas of the Upper Chena (χ^2 = 7.60, df = 3, P ≈ 0.06; Figure 4). There was a significant difference in length frequencies of fish marked versus those recaptured (D = 0.17, P ≈ 3.02×10^{-3}; Figure 9A). The maximal chi-squared statistic occurred at a stratification of 150 to 241 mm Fl for small fish and > 242 mm Fl for large fish. The summed estimate of abundance of wild and age 2 hatchery-reared fish in the Upper Chena was 29,269 fish(SE = 2,852 fish; Table 8). The proportion of age 2 hatchery-reared fish in catches from the Upper Chena section differed by size (χ^2 = 17.72, df = 1, P ≈ 2.60×10^{-5}; Table 9). There were 6.3% age 2 hatchery-reared fish in the small fish stratum and 2.4% age 2 hatchery-reared fish in the large fish stratum (Table 9). Abundance of wild fish was 27,840 fish (SE = 2,695 fish) and abundance of age 2 hatchery-reared fish was 1,429 fish (SE = 228 fish) or 4.9% of the combined abundance (Table 9).

There was a significant difference in length frequencies of fish marked versus those examined for marks (D = 0.05, P ≈ 0.03; Figure 9B). Therefore the second sample (recapture event) was used to estimate age composition of wild fish and size compositions of wild and age 2 hatchery-reared fish. Age 4 and age 3 fish were most abundant in this section of river (Table 10). Ages 2 through 7 comprised 96% of abundance, with very few fish older than age 9. Similarly, stock size fish comprised 76% of abundance in the Upper Chena while only 4% of fish were of preferred size (Table 11). Size composition of age 2 hatchery fish was primarily comprised of fish between 210 and 250 mm FL (79.8%).

Age 1 Hatchery-Reared Fish:

A total of 1,075 age 1 hatchery-reared fish were marked, 992 fish were examined for marks, and 38 were recaptured during mark-recapture sampling. Recapture-to-catch ratios did significantly differ among four areas of the Upper Chena (χ^2 = 10.41, df = 3, P ≈ 0.02; Figure 7). However, the summed estimate of abundance for the four areas (27,656 fish) did not differ markedly from the combined estimate of abundance (27,371 fish). Therefore, abundance, and size compositions were estimated for all four areas combined. There was no significant difference in length frequencies of fish marked versus those recaptured (D = 0.19, P ≈ 0.15; Figure 10A). The estimated abundance of age 1 hatchery-reared fish in the Upper Chena was 27,371 fish (SE = 4,242 fish).

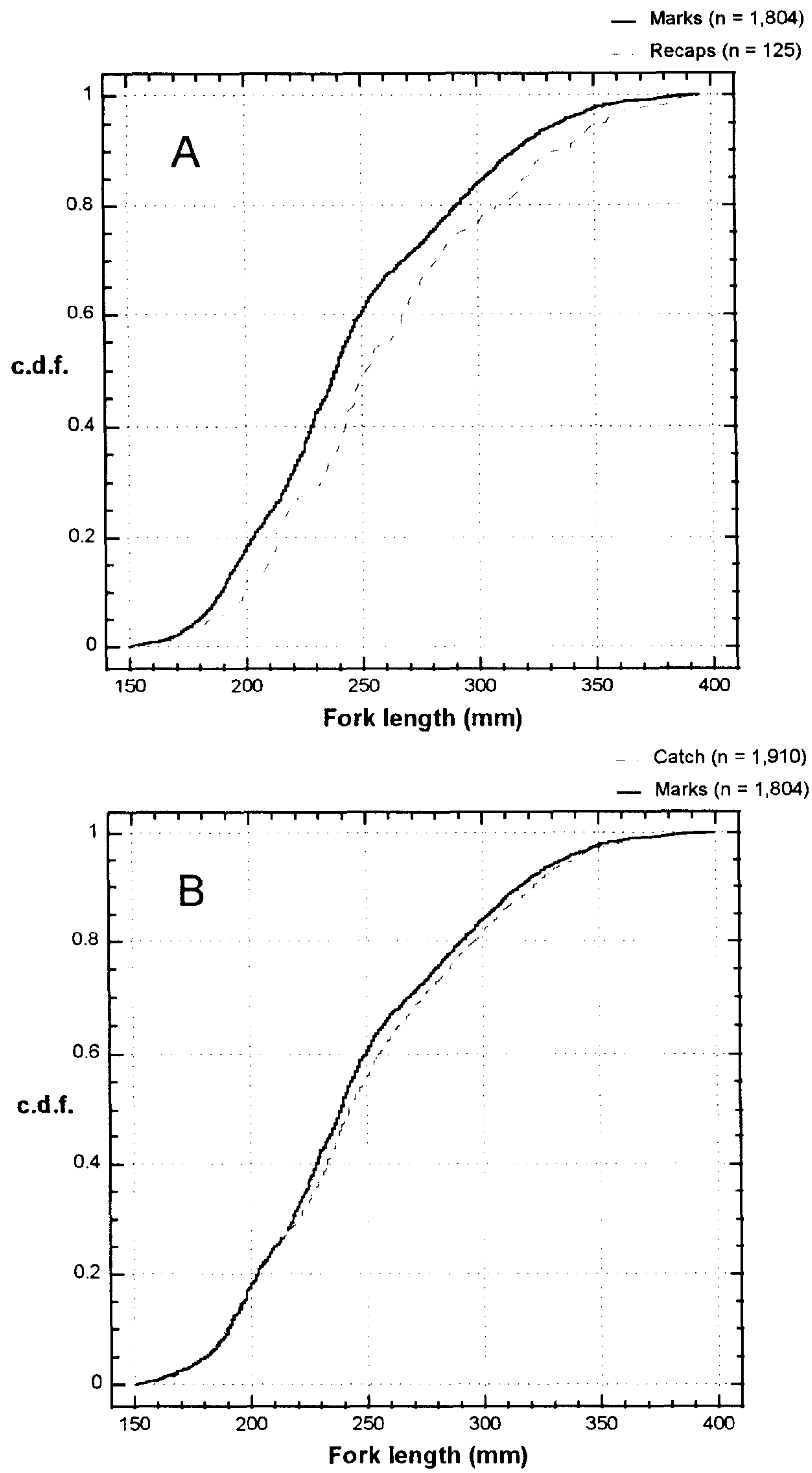

Figure 9.-Cumulative density functions (c.d.f.) of fork length of wild and age 2 hatchery-reared Arctic grayling marked, captured, and recaptured in the Upper Chena section of the Chena River, 19 through 29 July 1994.

Table 8.-Capture probabilities and estimated abundance in two size categories used for population estimation of wild and age-2 hatchery-reared Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 19 through 29 July 1994.

	Size category		
	150 to 241 mm	≥242 mm	Total
Mark(n_1)	961	846	1,807
Catch(n_2)	941	971	1,9121
Recap(m_2)	47	78	125
m_2/n_1[a]	0.05	0.08	0.06
N[b]	18,860	10,409	29,269
SE[N][c]	2,625	1,115	2,852

a m_2/n_1 is the probability of capture.
b N is the estimated abundance in a size category.
c SE[N] is the standard error of N.

Table 9.-Estimates of apportioned abundance in two size categories used for population estimation of wild and age-1 hatchery-reared Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 19 through 29 July 1994.

	Size category		
	150-241 mm	≥242 mm	Total
Catch[a]			
AGE2	59	23	82
Wild	882	948	1,830
All	941	971	1,912
p_{AGE2}[b]	0.063	0.024	0.043
SE	0.008	0.005	0.005
Abundance[c]			
AGE2	1,182	247	1,429
SE	221	101	228
Wild	17,677	10,162	27,840
SE	2,465	1,090	2,695
All	18,860	10,409	29,269
SE	2,625	1,115	2,852

a Catches are of age-2 hatchery-reared fish (AGE2), wild fish (Wild), and wild plus age-2 hatchery-reared fish (All).

b p_{AGE2} is the proportion of age-2 hatchery-reared fish in the catches of All fish (AGE2 divided by All).

c Abundances are of age-2 hatchery-reared fish (AGE2), wild fish (Wild), and wild plus age-2 hatchery-reared fish (All).

Table 10.-Estimates of adjusted age composition and abundance by age class with standard errors for wild Arctic grayling (≥150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 26 through 29 July 1994.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE	CV	N[c]	SE	CV
2	35	0.06	0.01	17.4	1,662	330	19.9
3	185	0.31	0.03	8.1	8,650	1,092	12.6
4	289	0.38	0.02	4.9	10,524	1,142	10.8
5	60	0.05	0.01	15.7	1,506	277	18.4
6	73	0.06	0.01	15.3	1,768	319	18.0
7	105	0.09	0.01	13.8	2,533	427	16.8
8	24	0.02	<0.01	22.8	574	142	24.7
9	15	0.01	<0.01	27.9	359	106	29.4
10	6	0.01	<0.01	42.3	145	63	43.2
11	3	<0.01	<0.01	57.7	72	42	58.2
12	2	<0.01	<0.01	70.6	47	34	70.9
Total	797	1.00	---	---	27,840	2,695	9.7

[a] n = number of Arctic grayling sampled at age.

[b] p = estimated adjusted proportion of Arctic grayling at age in the population.

[c] N = estimated population abundance of Arctic grayling at age.

Table 11.-Summary of Relative Stock Density (RSD) indices of wild Arctic grayling (≥ 150 mm FL) captured in the Upper Chena section, 1994.

	RSD category[a]				
	S	Q	P	M	T
Number sampled	1,210	198	13	0	0
RSD	0.85	0.14	0.01	0.00	0.00
Adjusted RSD[b]	0.86	0.13	0.01	0.00	0.00
SE	0.01	0.01	<0.01	0.00	0.00
N	14,200	2,191	144	0	0
SE	1,085	271	43	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): stock(S) - 150 mm FL; quality(Q) - 270 mm FL; preferred(P) - 340 mm FL; memorable(M) - 450 mm FL; and, trophy(T) - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. Standard error of RSD is for the adjusted estimate.

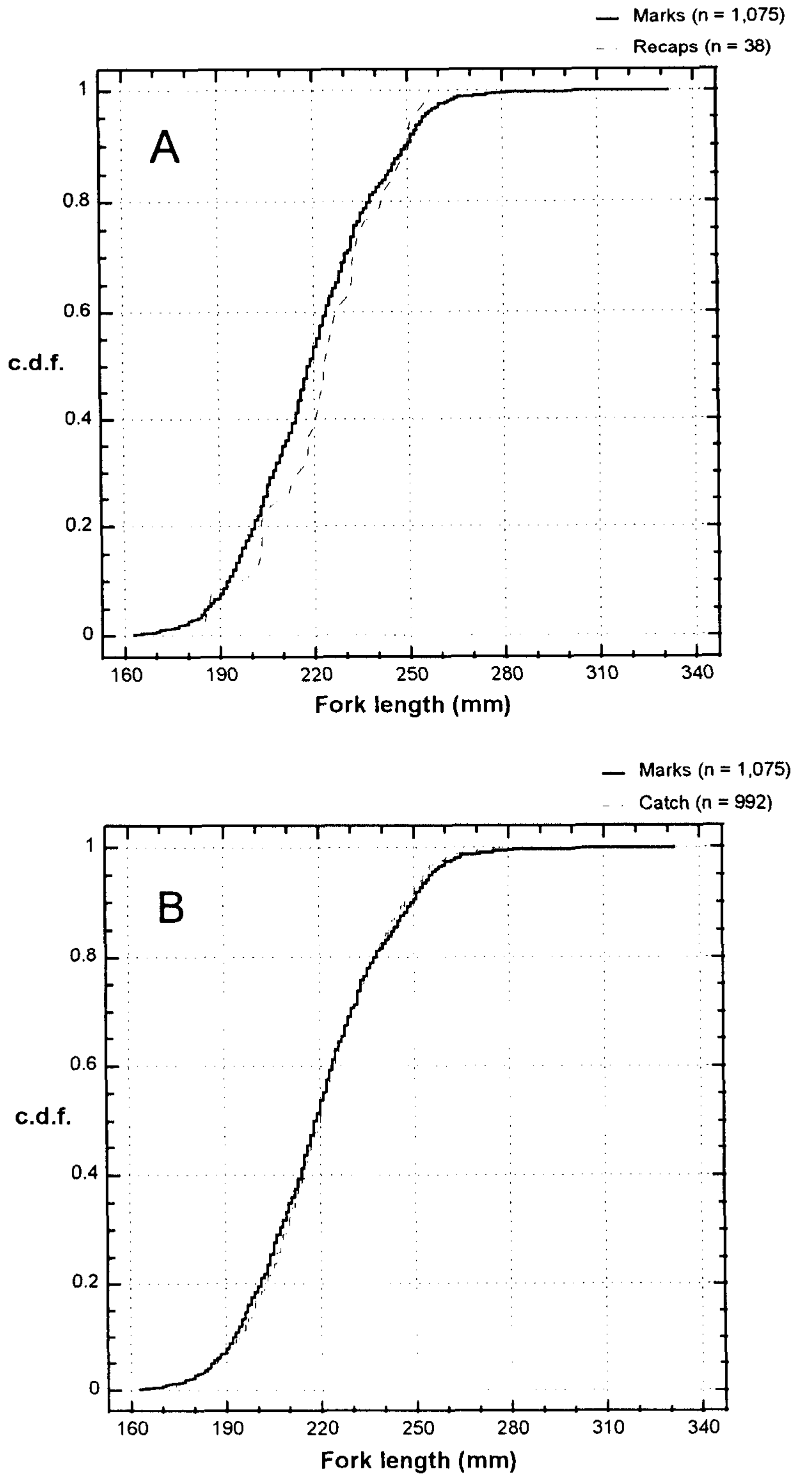

Figure 10.-Cumulative density functions (c.d.f.) of fork length of age 1 hatchery-reared Arctic grayling marked, captured, and recaptured in the Upper Chena section of the Chena River, 19 through 29 July 1994.

There was no significant difference in length frequencies of fish marked versus those examined for marks ($D = 0.05$, $P \approx 0.11$; Figure 10B). Therefore either sample (marking event or recapture event) could be used to estimate age and size composition. Composition data were estimated from the recapture event for wild and age 2 hatchery-reared fish, so size composition and proportion of hatchery-reared fish by electrofishing run estimates were calculated from the recapture event. Most age 1 hatchery-reared fish were between 190 and 240 m FL (76.5%). Based on abundances of wild and hatchery-reared fish, the proportion of age 1 hatchery-reared fish in the Upper Chena was 0.48 (SE = 0.05) or 48%.

CHENA RIVER

Summing estimated abundances from the Lower and Upper Chena sections, there was 44,375 wild fish (SE = 2,964 fish), 3,699 age 2 hatchery-reared fish (SE = 307 fish), and 41,928 age 1 hatchery-reared fish (SE = 5,105 fish) in the lower 152 km of the Chena River in July of 1994. The overall proportion of hatchery-reared fish was 0.51 (SE = 0.03) or 51%. Age 1 hatchery-reared fish comprised 47% (0.47, SE = 0.03) and age 2 hatchery-reared fish comprised 4% (0.04, SE = <0.01) of total abundance. Age 4 fish comprised 34% of the estimated abundance of wild fish, with age 3 fish accounting for 29% of abundance (Table 12). Eighty percent of estimated abundance was of stock size fish, with only 3% of preferred size (Table 13). Abundance of age 3 and older fish was 39,414 fish (SE = 1,834 fish; Table 14). Survival rate of age 3 and older fish from 1993 to 1994 was 0.77 (SE = 0.08; Table 14). Recruitment from 1993 to 1994 (age 3 fish) was 13,113 fish (SE = 1,183 fish). Data files used to estimate abundance, and age and size compositions are listed in Appendix B1.

During stock assessment in July, age 1 hatchery-reared fish were found in all but one of 66 electrofishing runs (Figure 11). Highest estimated abundance of age 1 hatchery-reared fish occurred between river kilometer 112 and 130. The proportion of age 1 hatchery-reared fish in the Chena River also varied greatly among electrofishing runs (Figure 12). Although the overall proportion of age 1 hatchery-reared fish was 0.47, estimates ranged from 0.00 (SE = 0.00) at river kilometer 3 to 0.82 (SE = 0.04) at river kilometer 70 (Figure 12). Age 2 hatchery-reared fish were found predominantly in the Lower Chena section, with highest estimated abundance between river kilometer 13 and 40 (Figure 11).

Estimated survival of age 1 hatchery-reared fish from time of release to time of stock assessment was 0.68 (SE = 0.08). Average length of age 1 hatchery-reared fish during stock assessment was 216 mm FL (SD = 21 mm FL, SE = 1 mm FL). Estimated survival of age 2 hatchery-reared fish from time of release in June 1993 (64,936 fish released) to time of stock assessment in July 1994 was 0.06 (SE = <0.01). Annual survival of age 2 hatchery-reared fish (July 1993 to July 1994) was 0.11 (SE = 0.01). Average length of age 2 hatchery-reared fish during stock assessment was 228 mm FL (SD = 18 mm FL, SE = 1 mm FL). Average growth was 9 mm (SD = 8 mm) for 11 age 2 hatchery-reared fish, tagged during stock assessment in 1993 and recovered during stock assessment during 1994. Average change in recovery location from 1993 to 1994 for these 11 fish was 18 km downstream (SE = 5 km).

Table 12.-Estimates of adjusted age composition and abundance by age class with standard errors for wild Arctic grayling (≥150 mm FL) captured by pulsed-DC electrofishing from the Chena River, 5 through 29 July 1994.

Age	p[a]	SE	N[b]	SE
2	0.11	0.01	4,961	487
3	0.30	0.02	13,113	1,183
4	0.34	0.01	15,137	1,216
5	0.07	0.01	3,178	343
6	0.07	0.01	3,046	361
7	0.07	0.01	3,238	440
8	0.02	<0.01	851	153
9	0.01	<0.01	493	112
10	0.01	<0.01	231	70
11	<0.01	<0.01	82	43
12	<0.01	<0.01	47	34
Total	1.00	---	44,375	2,964

[a] p = estimated adjusted proportion of Arctic grayling at age in the population.

[b] N = estimated population abundance of Arctic grayling at age.

Table 13.-Summary of Relative Stock Density (RSD) indices of wild Arctic grayling (≥ 150 mm FL) captured in the Chena River, 1994.

	RSD category[a]				
	S	Q	P	M	T
Number sampled	2,425	717	109	0	0
RSD	0.75	0.22	0.03	0.00	0.00
Adjusted RSD[b]	0.80	0.17	0.03	0.00	0.00
SE	0.02	0.02	<0.01	0.00	0.00
N	35,439	7,762	1,174	0	0
SE	2,498	857	180	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): stock(S) - 150 mm FL; quality(Q) - 270 mm FL; preferred(P) - 340 mm FL; memorable(M) - 450 mm FL; and, trophy(T) - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. Standard error of RSD is for the adjusted estimate.

Table 14.-Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1986-1994 for wild Arctic grayling (≥ age 3) in the lower 152 km of the Chena River.

Year	N[a]	SE	S[b]	SE	B[c]	SE
1986	61,581	26,987	43.9	20.1		
1987	29,580	3,525	57.1	8.1	2,526	358
1988	20,268	1,214	58.7	9.0	3,373	529
1989	16,236	1,618	75.4	11.0	4,332	491
1990	29,130	4,373	74.7	13.2	16,881	4,172
1991	24,657	2,082	78.8	8.2	2,882	368
1992	25,211	1,333	60.1	6.2	5,773	591
1993	34,209	2,969	76.9	7.8	19,066	2,647
1994	39,414	1,834			13,113	1,183

[a] N is the abundance of age 3 and older Arctic grayling.

[b] S is the survival from that year to the next year.

[c] B is recruitment of age 3 Arctic grayling during that year.

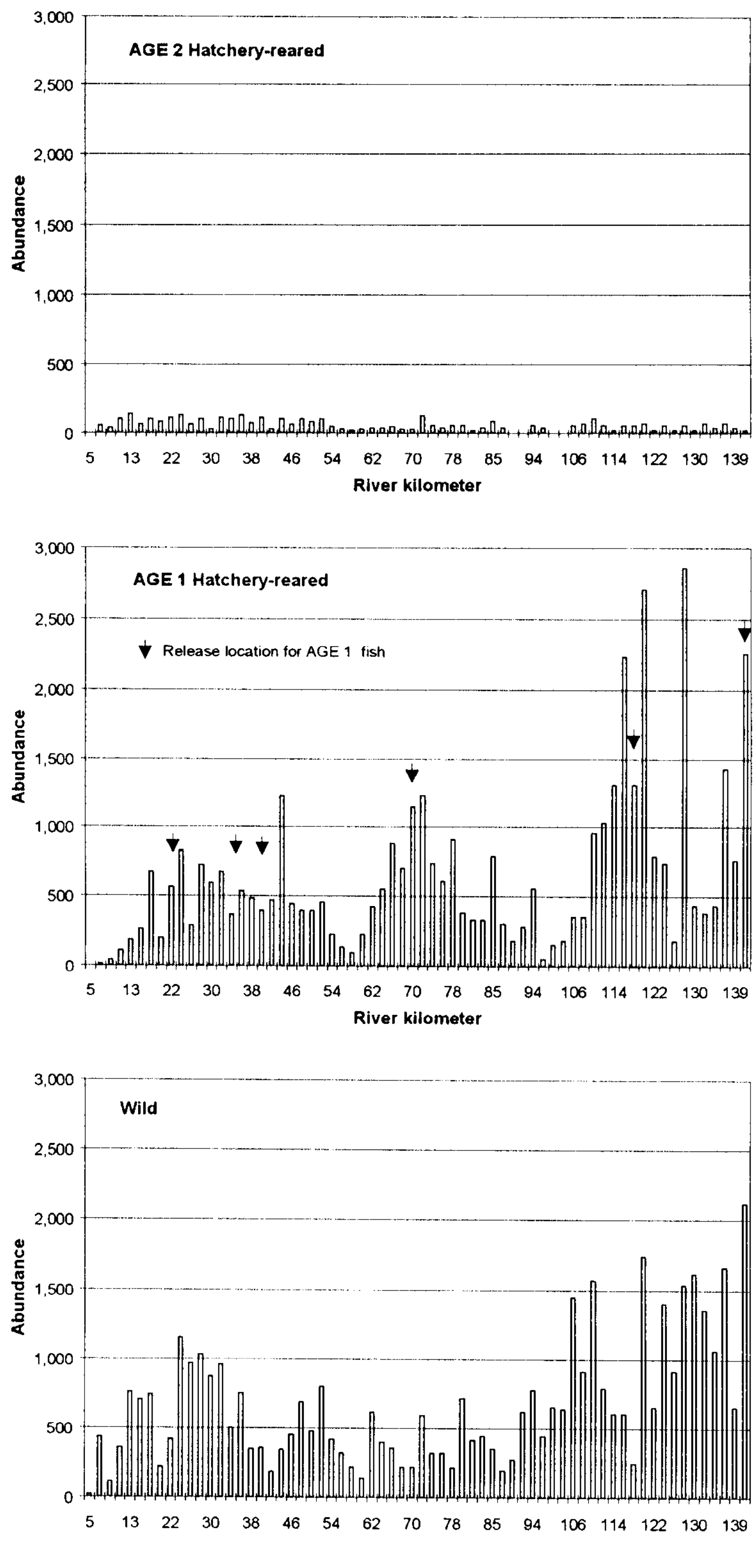

Figure 11.-Estimated abundance of wild and hatchery-reared Arctic grayling (≥ 150 mm FL) by river kilometer of the Chena River during 5 through 29 July 1994.

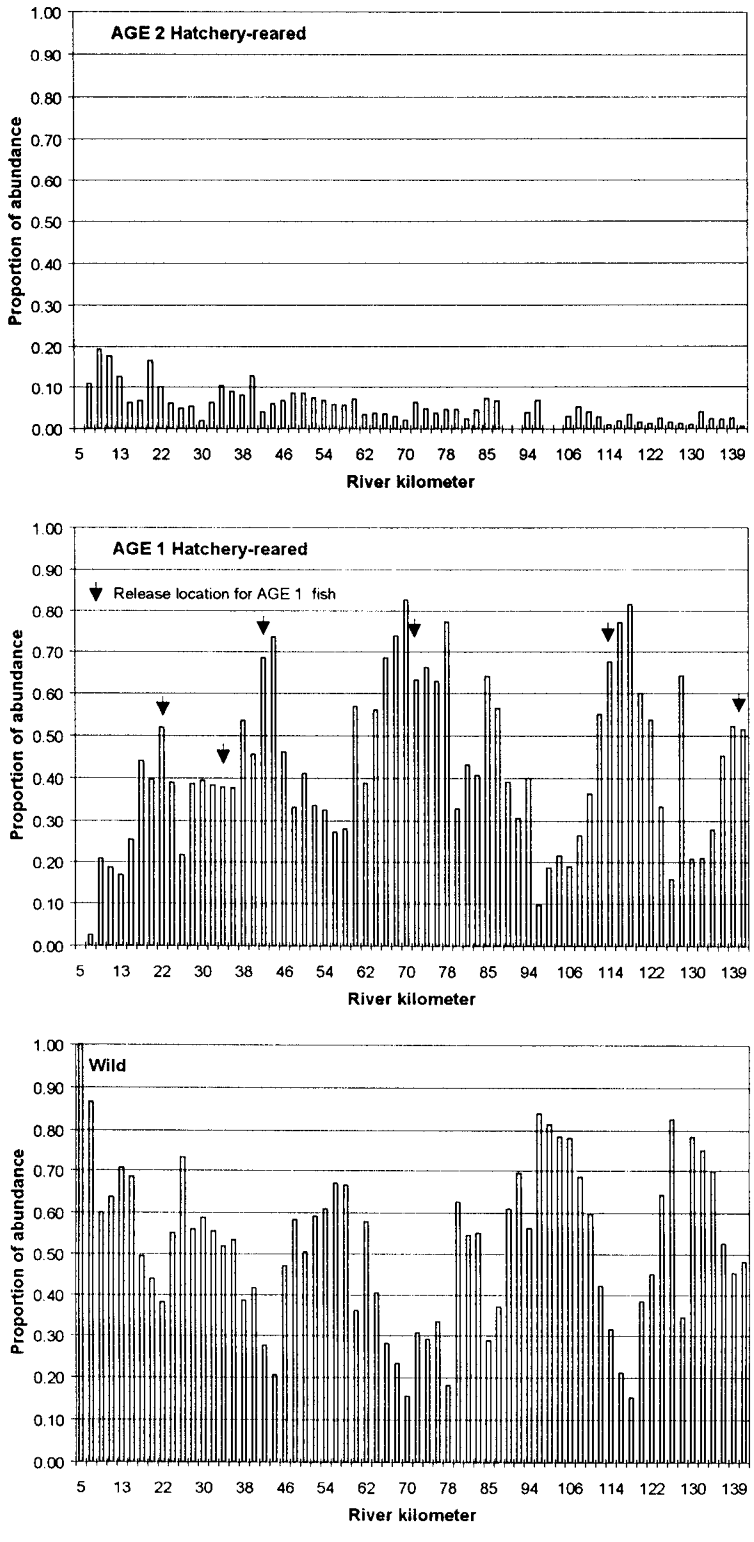

Figure 12.-Estimated proportions of wild and hatchery-reared Arctic grayling (≥ 150 mm FL) by river kilometer of the Chena River during 5 through 29 July 1994.

DISCUSSION

STOCK STATUS

Based on historic estimates of recruitment (1979 through 1990 average of 13,425 fish), the Chena River had an average level of recruitment in 1994. Recruitment was above average in 1993 (Clark 1994), so that recruitment for 1993-1994 represents the first time since 1980-1981 that recruitment was at least average for two consecutive years (see Clark 1992a). The result of two years of favorable recruitment was that abundance of age 3 and older fish was the highest since 1986. However, abundance of mature Arctic grayling (age 5 and older) remained below average in 1994 (abundance = 11,166 fish, SE = 696 fish; 1979-1990 average = 16,561 fish). Continuance of catch-and-release regulations will allow recruits from 1993 and 1994 to enter the spawning population in 1995 and 1996. Favorable survival conditions during 1995 and 1996 should result in spawner abundance well above average during these years. Overall abundance may decline in 1995, despite catch-and-release fishing, because recruitment is projected to be below average for 1995. Above average recruitment is projected for 1996. These projections are based on the relation between recruits-per-spawner and stream flows during spawning, hatching, and rearing (Clark 1992a).

Harvest of Arctic grayling in the recreational fishery was prohibited by regulation during 1993 and 1994, so that the estimate of total survival (0.77 in 1994) can be considered an estimate of natural survival. The average natural survival rate during catch-and-release regulations (1991-1994) was 0.71 (instantaneous rate of natural mortality of 0.34), comparable to the average natural survival rate prior to catch-and-release (1979-1991) of 0.78 (natural mortality rate of 0.31). Looking at total survival, the average rate during 1979-1987 (no special regulations) was 0.45 (Table 15). Average total survival rate during 1987-1991 (12 inch or 305 mm minimum length limit) was 0.66, and during 1991-1994 (catch-and-release) was 0.71 (Table 15).

Future research on Arctic grayling in the Chena River should focus on examination of regulatory policies that allow sustainable yield with some level of consumptive harvest. Criteria for optimization of the policy might include minimization of variance in abundance over time, minimization of variance in harvest about some threshold level of harvest over time, or a combination of these criteria. Outputs from the model would likely be advice concerning sustainable exploitation rates. Unfortunately, formulation of regulatory policy (bag limits, length limits, seasons, areas) from a desired exploitation rate requires a potentially long-term set of management experiments.

HATCHERY-REARED FISH

From the time of release in June 1994 and time of stock assessment in July 1994, age 1 hatchery-reared fish experienced a reduction in abundance from 60,435 fish to 41,928 fish (32% reduction). This reduction is higher than might be expected, given the short period of time (between 1 and 6 weeks) at large. However, the reduction in abundance estimated in 1994 was less than in 1993 when abundance was reduced 49% in 4 to 6 weeks (Clark 1994). As was noted in 1993, there was movement upstream and downstream from release locations in June to other areas in July (see Figure 11).

Table 15.-Summary of survival and mortality estimates for Arctic grayling (age 3 and older) in the Chena River by periods of similar regulatory policy, 1979-1994.

	Time Period			
	1979-1987	1987-1991	1991-1994	1979-1994
Policy[a]	5 fish bag limit	305 mm length limit	catch-and-release	Average[d]
Annual[b]				
s	0.45	0.66	0.71	0.55
m	0.65	0.88	0.71	0.72
h	0.31	0.25	0.00	0.24
Instantaneous[c]				
Z	0.79	0.42	0.34	0.60
M	0.34	0.11	0.34	0.28
F	0.45	0.31	0.00	0.32

[a] Regulatory policies are: 5 fish bag limit = no closed season, 5 fish daily bag limit, 10 fish possession limit, no size limit; 305 mm length limit = catch-and-release during 1 April - first Saturday in June, 5 fish daily bag and possession during open season of 1987-1989, 2 fish daily bag and possession during open season 1990-1991, catch-and-release year around from first bridge Chena Hot Springs Road to mouth of South Fork, 305 mm (12 inch) minimum length limit, unbaited artificial lures only, single hook only above Chena River Dam; catch-and-release = catch-and-release for entire drainage for entire year.

[b] Annual rates are: s = average annual total survival rate; m = average annual natural survival rate; and, h = average annual harvest rate. Rates are related by: $s = m(1 - h)$.

[c] Instantaneous rates are: Z = total mortality rate; M = natural mortality rate; and, F = fishing mortality rate. Rates are related by. $Z = M + F$.

[d] All averages (across years and across policies) are geometric means.

Similar to 1993, a high proportion (not estimated) of male hatchery-reared fish appeared to extrude a substance similar to milt when handled during stock assessment. Although none of this substance was collected for confirmation, perhaps the rapid growth experienced in hatchery rearing caused premature formation of active gonads. In 1994 only, a smaller but noticeable proportion of female hatchery-reared fish extruded what appeared to be unviable eggs. Undoubtedly, rapid growth in the hatchery caused early maturation of ovaries. These fish were not released into the Chena River until June, well after the spawning period for wild fish (generally mid-May through early June); perhaps retention of gametes well into summer increased stress and reduced survival of these fish.

Survival of age 2 hatchery-reared fish was much lower than anticipated given the size of fish at release (100 g), genetic origin (Chena River brood), conditions during release (low, warm water), and lack of consumptive harvest. Projections of survival were approximately one-half of the survival rate of wild fish or approximately 35% per year, while the actual survival rate was only 6%. Of survivors that were marked with a Floy tag in 1993 and recovered in 1994 (n = 12 of 607 examined), most had moved some distance downstream from the release location (average movement of 18 km downstream, range = 5 km upstream to 48 km downstream). Growth of Floy tagged survivors averaged 9 mm (range = 0 to 26 mm; see also Figure 13). Average increment of growth for wild Arctic grayling of this size (~225 mm or approximately age 4) is 25 mm (see Appendix A6). Lack of growth and downstream movements of survivors may be indicative of starvation and disorientation as causes for high mortality of releases. In addition, one northern pike *Esox lucius*, killed during electrofishing, was found to have eaten an age 2 hatchery reared fish. Burbot *Lota lota*, sheefish *Stenodus leucichthys* and a variety of fish-eating birds may have also preyed on these fish.

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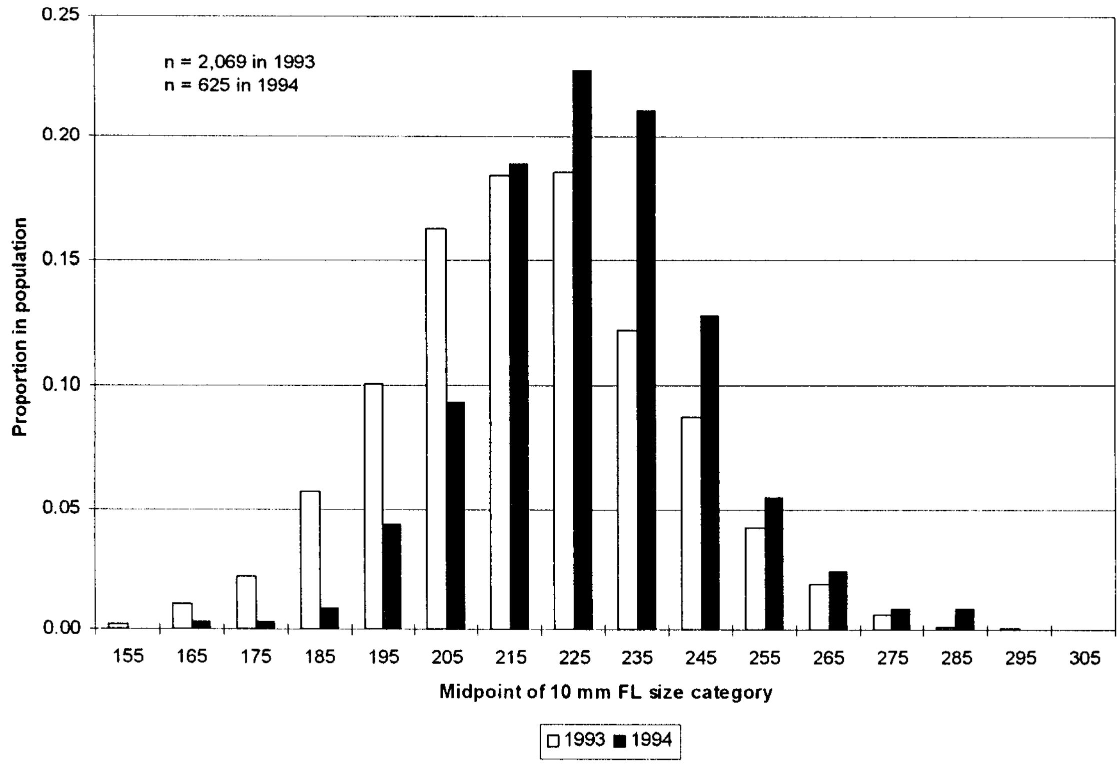

Figure 13.-Size composition of age 2 hatchery-reared Arctic grayling during stock assessment in 1993 (from Clark 1994) and stock assessment in 1994.

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APPENDIX A

Historic Data Summary

Appendix A1. Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1994.

Year	Type of Data[a]	Source Document
1955	CC	Warner (1959)
1956	CC	Warner (1959)
1957	CC	Warner (1959)
1958	CC	Warner (1959)
1967	AL, CC, POP	Van Hulle (1968)
1968	AL, CC, POP	Roguski and Winslow (1969)
1969	AL, CC, POP	Roguski and Tack (1970)
1970	CC, POP	Tack (1971)
1971	POP	Tack (1972)
1972	CC, POP	Tack (1973)
1973	AL, POP	Tack (1974)
1974	AL, CC, POP	Tack (1975)
1975	AL, CC, POP	Tack (1976)
1976	AL, CC, POP	Hallberg (1977)
1977	AL, CC, POP	Hallberg (1978)
1978	AL, CC, POP	Hallberg (1979)
1979	AL, CC, POP	Hallberg (1980)
1980	AL, CC, POP	Hallberg (1981)
1981	AL, CC, POP	Hallberg (1982)
1982	AL, CC, POP	Holmes (1983)
1983	AL, CC, POP	Holmes (1984)
1984	AL, CC, POP	Holmes (1985)
1985	AL, CC, POP	Holmes et al. (1986)
1986	CC	Clark and Ridder (1987a)
	AL, POP	Clark and Ridder (1987b)
1987	CC	Baker (1988)
	AL, POP	Clark and Ridder (1988)
1988	CC	Baker (1989)
	AL, POP	Clark (1989)
1989	CC	Merritt et al. (1990)
	AL, POP	Clark (1990)
1990	AL, POP	Clark (1991)
1991	AL, POP	Clark (1993)
	CC	Hallberg and Bingham (1992)
1992	AL, POP	Clark (1993)
1993	AL, POP	Clark (1994)
1994	AL, POP	Clark (this report)

[a] CC = Creel census estimates;
AL = age and size composition estimates; and,
POP = population abundance estimates.

Appendix A2. Chena River study sections used from 1968 to 1985[a].

Section Number	Section Name	River Kilometers	Length in Kilometers
1	River mouth to University Ave.	0-9.6	9.6
2A	University Ave. to Peger Road	9.6-12.8	3.2
2B	Peger Road to Wendell Street	12.8-17.6	4.8
3	Wendell St. to Wainwright Bridge	17.6-23.2	5.6
4	Wainwright Bridge to Badger Slough	23.2-34.4	11.2
5	Badger Slough		26.4
6	Badger Slough to Little Chena R.	34.4-39.2	4.8
7	Little Chena River		98.4
8	Little Chena to Nordale Slough	39.2-49.6	10.4
DS	Nordale Slough to Bluffs	49.6-88.8	39.2
9B	Bluffs to Bailey Bridge	88.8-100.8	12.0
10	Bailey Bridge to Hodgins Slough	100.8-126.4	25.6
11	Hodgins Slough to 90 Mi. Slough	126.4-144.0	17.6
12	90 Mi. Slough to First Bridge	144.0-147.2	3.2
13	First Bridge to Second Bridge	147.2-151.2	4.0
14	Second Bridge to North Fork	151.2-163.2	12.0
15	North Fork of Chena River		56.0
16	East Fork of Chena River		99.2
17	West Fork of Chena River		56.0

[a] Taken from Hallberg 1980.

Appendix A3. Summary of population abundance estimates of Arctic grayling (≥ 150 mm FL) in the Chena River, 1968-1994.

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1968	Summer?	2	SN	411/km	393-1,209
	Summer?	6	SN	283/km	228-381
1969	June?	2	SN	596/km	474-850
	June?	6	SN	571/km	439-816
1970	7/02-7/10	2	SN	919/km	690-1,519
	5/26-5/30	6	SN	373/km	346-408
	6/08-7/08	9B	SN	1,005/km	803-1,411
	6/07-7/07	10	SN	1,171/km	876-1,957
1971	8/30-9/03	2A	SN	300/km	192-1,157
	6/02-6/07	2B	SN	1,302/km	958-2,305
	8/30-9/03	2B	SN	2,338/km	1,753-3,897
	6/21-6/24	6	SN	189/km	161-233
1972	6/22-6/26	2A	SN	309/km	236-489
	6/22-6/26	2B	SN	608/km	493-828
	6/19-6/20	6	SN	159/km	124-235
	6/27-6/29	DS	SN	812/km	604-1,393
1973	7/10-7/13	2A	SN	293/km	218-502
	7/03-7/14	2B	SN	424/km	354-545
	7/16-7/17	6	SN	243/km	203-312
	7/18-7/19	DS	SN	500/km	379-806
1974	6/26-6/28	2A	SE	65/km	36-372
	6/25-6/28	2B	SE	488/km	207-1,378
	8/13-8/15	6	SE	100/km	71-164
	7/09-7/11	DS	SE	263/km	221-326
1975	7/10-7/14	6	SE	191/km	114-589
1976	7/19-7/21	2A	SE	258/km	223-307
	7/22-7/24	2B	SE	409/km	323-556
	7/28-7/30	6	SE	163/km	153-175
	8/04-8/06	DS	SE	306/km	285-329
1977	7/05-7/08	2A	SE	318/km	298-343
	7/11-7/14	2B	SE	318/km	280-370
	7/18-7/21	6	SE	173/km	170-177
	7/26-7/30	DS	SE	315/km	283-359
1978	7/14-7/17	2A	SE	69/km	44-156
	7/25-7/28	2B	SE	162/km	148-179
	7/10-7/13	6	SE	226/km	210-243
	8/08-8/11	DS	SE	345/km	333-359

- continued -

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Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1979	7/01-7/03	2A	SE	57/km	45-76
	6/26-6/30	2B	SE	201/km	188-216
	8/20-8/23	8A	SE	177/km	161-197
	7/17-7/20	DS	SE	193/km	144-288
1980	7/01-7/04	2B	SE	308/km	229-471
	7/14-7/17	8A	SE	190/km	154-248
	7/29-8/01	DS	SE	236/km	200-287
	8/12-8/15	10B	SE	842/km	640-1,234
1981	8/07-8/10	2B	SN	262/km	223-392
	8/03-8/06	8A	SN	224/km	164-309
	8/11-8/14	DS	SN	302/km	174-440
	7/21-7/24	10B	SN	869/km	466-1,778
1982	7/16-7/20	2B	SN	116/km	79-177
	7/13-7/15	8A	SN	87/km	60-132
	7/23-7/27	DS	SN	232/km	113-579
	7/28-7/30	10B	SN	875/km	529-1563
1983	7/13-7/15	2B	SN	216/km	168-265
	7/05-7/07	8A	SN	119/km	81-545
	7/8,7/11-7/12	DS	SN	209/km	149-303
	7/26-7/28	10B	SN	911/km	647-1,338
	7/19-7/21	12	SN	208/km	138-332
1984	7/16-7/18	2B	SN	211/km	167-268
	7/3,7/05-7/06	8A	SN	139/km	95-215
	7/09-7/11	DS	SN	179/km	124-273
	7/19-7/20	10B	P	493/km	275-1,003
	7/31,8/02-8/03	12	SN	1,318/km	449-6,592
1985	7/10-7/17	2B	SN	189/km	92-287
	6/26-7/02	8A	SN	271/km	189-360
	7/03-7/08	DS	SN	333/km	234-432
	7/22-7/31	10B	SN	1,156/km	304-3,035
	6/12-6/24	12	SN	1,092/km	552-1,643
1986	7/07-8/06	WC	EXP	61,581	SE = 26,987
1987	6/27-7/30	WC	EXP+P	31,502	SE = 3,500
1988	6/26-8/04	WC	EXP+P	22,204	SE = 2,092
1989	7/10-8/03	WC	EXP+P	19,028	SE = 1,578
1990	7/02-8/03	WC	EXP+P	31,815	SE = 4,880
1991	7/08-8/01	WC	P	26,756	SE = 3,286
1992	7/06-7/30	WC	P	29,349	SE = 2,341
1993	7/06-7/29	WC	P	39,618	SE = 4,836
1994	7/05-7/29	WC	P	44,375	SE = 2,964

[a] Areas are taken from Hallberg (1980); WC = Whole Chena River (lower 152 km).

[b] Estimators are: SN = Schnabel; SE = Schumacher-Eschmeyer; P = Petersen (Ricker 1975); EXP = Expanded estimates (Clark and Ridder 1987b); EXP+P = expanded estimates and a Petersen estimate (Clark and Ridder 1988).

[c] Confidence is either the 95% confidence interval or the standard error (SE) of the estimate.

Appendix A4. Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, 1974-1989, and 1991.

Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1955	ND	Lower Chena	---	---	0.89	226
1956	ND	Lower Chena	---	---	0.95	251
1957	ND	Lower Chena	---	---	0.62	246
1958	ND	Lower Chena	---	---	0.88	226
1967	4/10 to 8/11	Entire Chena	12,885	---	0.32	245
1968	5/01 to 9/02	Entire Chena	10,269	5,643	0.55	251
1969	7/01 to 9/30	Entire Chena	7,998	7,686	0.96	263
1970	5/01 to 5/30 and 7/01 to 8/31	Entire Chena	12,518	6,770	0.54	---
1972	5/25 to 8/27	Lower Chena	13,116	10,099	0.77	---
1974	7/01 to 8/31	Upper Chena	11,680	18,049	1.72	---
1975	6/01 to 8/31	Upper Chena	22,657	14,067	0.62	252
1976	6/01 to 8/31	Upper Chena	10,762	4,161	0.39	230
1977	6/01 to 8/31	Upper Chena	13,563	9,406	0.71	208
1978	5/29 to 8/31	Upper Chena	10,508	6,898	0.65	222
1979	6/01 to 8/31	Upper Chena	12,564	8,544	0.69	240
1980	5/08 to 9/30	Upper Chena	20,827	16,390	0.78	256
1981	5/01 to 8/31	Upper Chena	15,896	13,549	0.80	---
1982	5/01 to 9/15	Upper Chena	20,379	12,603	0.62	248
1983	5/01 to 9/15	Upper Chena	19,018	10,821	0.58	260
1984	5/06 to 9/15	Upper Chena	17,090	9,623	0.59	278
1985	5/08 to 9/05	Upper Chena	10,613	2,367	0.22	273
1986	5/10 to 9/15	Upper Chena	10,716	3,326	0.31	271
1987	5/18 to 9/15	Upper Chena	9,090	1,260	0.14	290
1988	5/14 to 9/13	Upper Chena	11,763	1,583	0.13	287
1989	5/19 to 9/13	Upper Chena	11,349	3,325	0.21	295
1991	5/18 to 7/31	Upper Chena[a]	3,201	---	---	280

[a] Only road km 43 through 73 of the Chena Hot Springs Road.

Appendix A5. Summary of age composition estimates of Arctic grayling in the Chena River, 1967-1969 and 1973-1994.

	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
Year	p[a]	SE[b]	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1967	0.10	0.02	0.13	0.02	0.13	0.02	0.06	0.01	0.17	0.02	0.25	0.02	0.11	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.09	0.03	0.21	0.04	0.24	0.04	0.25	0.04	0.13	0.03	0.03	0.01	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.38	0.07	0.12	0.05	0.16	0.05	0.06	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.06	0.02	0.13	0.02	0.61	0.03	0.18	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.04	0.01	0.11	0.02	0.12	0.02	0.44	0.03	0.25	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.13	0.04	0.25	0.05	0.13	0.04	0.26	0.05	0.19	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.10	0.02	0.24	0.03	0.29	0.03	0.15	0.02	0.09	0.02	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.06	0.02	0.34	0.03	0.45	0.03	0.08	0.02	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.15	0.02	0.38	0.03	0.22	0.03	0.21	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.11	0.02	0.20	0.03	0.45	0.03	0.17	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.02	0.01	0.12	0.02	0.39	0.03	0.28	0.03	0.13	0.02	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.16	0.02	0.13	0.02	0.40	0.02	0.12	0.02	0.12	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.06	0.01	0.30	0.03	0.11	0.02	0.35	0.03	0.09	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.01	0.01	0.07	0.01	0.11	0.01	0.45	0.02	0.08	0.01	0.17	0.02	0.06	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.19	0.02	0.07	0.01	0.12	0.02	0.41	0.02	0.08	0.01	0.09	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.02	0.00	0.16	0.01	0.11	0.01	0.14	0.01	0.32	0.01	0.10	0.01	0.10	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.07	0.01	0.09	0.01	0.13	0.01	0.04	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.05	0.01	0.08	0.01	0.60	0.03	0.07	0.01	0.05	0.01	0.10	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.09	0.02	0.15	0.02	0.12	0.02	0.42	0.04	0.07	0.01	0.06	0.01	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.15	0.02	0.23	0.03	0.14	0.02	0.14	0.02	0.22	0.03	0.06	0.01	0.04	0.01	0.03	0.01	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.08	0.04	0.53	0.08	0.10	0.03	0.08	0.02	0.07	0.02	0.09	0.02	0.02	0.01	0.01	0.00	<0.01	0.00	<0.01	0.00
1991	0.00	0.00	0.00	0.00	0.08	0.01	0.11	0.01	0.52	0.02	0.11	0.01	0.07	0.01	0.06	0.01	0.04	0.01	<0.01	0.00	<0.01	0.00	<0.01	0.00
1992	0.00	0.00	0.00	0.00	0.14	0.02	0.20	0.01	0.15	0.01	0.38	0.02	0.05	0.00	0.04	0.00	0.03	0.00	0.01	0.00	<0.01	0.00	<0.01	0.00
1993	0.00	0.00	0.00	0.00	0.14	0.01	0.48	0.03	0.12	0.01	0.09	0.01	0.11	0.02	0.02	0.00	0.02	0.00	0.01	0.00	0.01	0.00	<0.01	0.00
1994	0.00	0.00	0.00	0.00	0.11	0.01	0.29	0.03	0.34	0.03	0.07	0.01	0.07	0.01	0.07	0.01	0.02	0.00	0.01	0.00	<0.01	0.00	<0.01	0.00

[a] p = the proportion of the sample at age.

[b] SE = the standard error of p.

Appendix A6. Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1994.

	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
Year	n[a]	FL[b]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1967	30	25	41	135	41	186	17	243	51	272	77	293	32	321	15	335	0	---	0	---	0	---	0	---
1968	10	73	24	103	28	150	29	214	15	255	3	289	6	304	2	372	0	---	0	---	0	---	0	---
1969	0	---	0	---	0	---	11	191	19	236	6	273	8	304	3	317	3	356	0	---	0	---	0	---
1973	0	---	11	111	25	167	121	194	36	215	6	279	0	---	1	310	0	---	0	---	0	---	0	---
1974	0	---	12	130	32	169	37	199	133	217	76	236	12	259	1	315	0	---	0	---	0	---	0	---
1975	0	---	0	---	12	171	22	200	12	229	23	238	17	258	2	275	1	320	0	---	0	---	0	---
1976	0	---	26	144	61	175	74	194	39	221	24	249	28	270	4	308	0	---	0	---	0	---	0	---
1977	0	---	14	112	77	176	102	208	19	245	13	263	4	299	0	---	0	---	0	---	0	---	0	---
1978	0	---	39	128	102	167	59	206	56	230	9	256	2	290	1	325	0	---	0	---	0	---	0	---
1979	0	---	25	107	44	165	99	197	38	236	11	266	1	310	0	---	0	---	0	---	0	---	0	---
1980	0	---	4	114	31	154	97	198	71	231	33	259	12	292	3	327	0	---	0	---	0	---	0	---
1981	0	---	61	112	48	162	152	187	46	215	47	240	22	268	5	287	3	310	0	---	0	---	0	---
1982	0	---	19	105	88	137	34	190	105	215	26	251	11	279	7	305	6	337	0	---	0	---	0	---
1983	6	62	33	114	53	151	215	177	38	216	83	239	29	273	13	307	7	338	0	---	0	---	0	---
1984	0	---	82	97	32	153	54	182	179	213	36	226	40	257	7	275	6	321	0	---	0	---	0	---
1985	0	---	42	108	300	141	203	188	267	215	609	233	182	285	188	285	80	308	30	377	2	377	0	---
1986	0	---	40	109	104	164	755	184	79	220	110	251	153	270	42	301	22	318	5	330	1	346	0	---
1987	0	---	0	---	54	160	92	204	691	228	115	274	76	292	184	309	30	324	31	338	2	353	0	---
1988	0	---	7	108	135	172	238	216	181	239	707	260	118	288	95	313	110	325	35	347	7	337	2	374
1989	0	---	17	123	285	156	295	215	205	254	245	272	423	285	112	314	73	329	54	347	5	372		
1990	0	---	13	129	134	174	840	207	232	251	223	280	221	298	284	308	63	332	43	340	17	362	2	359
1991	0	---	0	---	143	177	211	215	863	241	227	273	177	298	199	303	135	316	23	335	19	347	3	338
1992	0	---	0	---	224	165	384	209	450	239	1046	262	214	288	157	307	134	312	57	321	20	338	6	347
1993	0	---	0	---	172	167	605	207	252	248	243	274	282	286	58	313	55	322	32	341	13	353	4	348
1994	0	---	0	---	274	177	512	199	721	236	228	258	202	277	178	296	52	309	29	331	15	332	4	367
Average		40		114		159		198		230		255		285		305		323		348		358		366

[a] n = sample size.

[b] FL = the arithmetic mean fork length in millimeters.

Appendix A7. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1994.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1972 (2A, 2B, 6, DS) - 6/19-6/22[b]					
Sample size	1,392	42	3	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	0.01	<0.01	<0.01	0.00	0.00
1973 (2A, 2B, 6, DS) - 7/3-7/19					
Sample size	176	7	0	0	0
RSD	0.96	0.04	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1974 (2A, 2B, 6, DS) - 6/25-8/15					
Sample size	889	58	0	0	0
RSD	0.94	0.06	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1975 (6) - 7/10-7/14					
Sample size	76	13	0	0	0
RSD	0.85	0.15	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
1976 (2A, 2B, 6, DS) - 7/19-8/6					
Sample size	613	59	1	0	0
RSD	0.91	0.09	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1977 (2A, 2B, 6, DS) - 7/5-7/30					
Sample size	916	30	0	0	0
RSD	0.967	0.03	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1978 (2A, 2B, 6, DS) - 7/10-8/11					
Sample size	841	20	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00

- continued -

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1979 (2A,2B,8A,DS) - 6/26-8/23					
Sample size	802	13	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	<0.01	<0.01	0.00	0.00	0.00
1980 (2B,8A,DS,10B) - 7/1-8/15					
Sample size	1,260	53	2	0	0
RSD	0.96	0.04	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1981 (2B,8A,DS,10B) - 7/21-8/14					
Sample size	1,247	42	1	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	<0.01	<0.01	<0.01	0.00	0.00
1982 (2B,8A,DS,10B) - 7/13-7/30					
Sample size	919	76	5	0	0
RSD	0.92	0.08	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1983 (2B,8A,DS,10B,12)- 7/5-7/28					
Sample size	1,560	152	10	0	0
RSD	0.91	0.09	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1984 (2B,8A,DS,10B,12) - 7/3-8/3					
Sample size	1,349	74	4	0	0
RSD	0.95	0.05	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1985 (2B,8A,DS,10B,12)-6/12-7/31					
Sample size[c]	ND	ND	ND	ND	ND
RSD	---	---	---	---	---
Standard Error	---	---	---	---	---
1986 (lower 152 km) - 7/7-8/6					
Sample size	1,268	160	29	0	0
RSD	0.87	0.11	0.02	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00

- continued -

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1987 (lower 152 km) - 6/27-7/30					
Sample size	1,678	693	154	0	0
RSD	0.67	0.27	0.06	0.00	0.00
Adjusted RSD[d]	0.78	0.19	0.03	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1988 (lower 152 km) - 6/26-8/4					
Sample size[f]	1,855	1,242	217	0	0
RSD	0.63	0.32	0.05	0.00	0.00
Standard Error	0.04	0.03	0.01	0.00	0.00
1989 (lower 152 km) - 7/10-8/3					
Sample size[f]	1,363	1,340	184	0	0
RSD	0.47	0.46	0.06	0.00	0.00
Adjusted RSD[d]	0.57	0.38	0.05	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1990 (lower 152 km) - 7/2-8/3					
Sample size[f]	2,239	1,389	255	0	0
RSD	0.58	0.36	0.06	0.00	0.00
Adjusted RSD[d]	0.75	0.21	0.04	0.00	0.00
Standard Error[e]	0.17	0.03	0.01	0.00	0.00
1991 (lower 152 km) - 7/8-8/1					
Sample size[f]	2,587	1,185	178	0	0
RSD	0.65	0.30	0.05	0.00	0.00
Adjusted RSD[d]	0.73	0.24	0.03	0.00	0.00
Standard Error[e]	0.01	0.01	<0.01	0.00	0.00
1992 (lower 152 km) - 7/6-7/30					
Sample size[f]	2,068	949	102	0	0
RSD	0.66	0.31	0.03	0.00	0.00
Adjusted RSD[d]	0.78	0.20	0.02	0.00	0.00
Standard Error[e]	0.04	0.02	<0.01	0.00	0.00

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	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1993 (lower 152 km) - 7/6-7/29					
Sample size[f]	1,370	613	84	0	0
RSD	0.66	0.30	0.04	0.00	0.00
Adjusted RSD[d]	0.79	0.19	0.02	0.00	0.00
Standard Error[e]	0.03	0.03	<0.01	0.00	0.00
1994 (lower 152 km) - 7/5-7/29					
Sample size[f]	2,425	717	109	0	0
RSD	0.75	0.22	0.03	0.00	0.00
Adjusted RSD[d]	0.80	0.17	0.03	0.00	0.00
Standard Error[e]	0.02	0.01	<0.01	0.00	0.00

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Year (sections sampled (taken from Hallberg 1980)) - sampling dates.

[c] Lengths were taken in 1985, but not reported in Holmes et al. (1986).

[d] RSD was adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

[e] Standard error is for adjusted RSD only.

[f] Sample sizes do not correspond to RSD proportions because RSD proportions are weighted by abundance estimates in a stratified design (Clark 1989) and RSD is adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

Appendix A8. Parameter estimates and standard errors of the von Bertalanffy growth model[a] for Arctic grayling from the Chena River, 1986-1993.

Parameter	Estimate	Standard Error
L_∞[b]	400	9
K[c]	0.18	0.01
t_o[d]	-1.11	0.14
$Corr(L_\infty,K)$[e]	-0.97	---
$Corr(L_\infty,t_o)$	-0.86	---
$Corr(K,t_o)$	0.95	---
Sample size	11,768	

[a] The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_\infty(1 - exp(-K(t - t_o)))$. The parameters of this model were estimated with data collected during 1986 through 1993. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age 2 through age 12.

[b] L_∞ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] t_o represents the hypothetical age at which a fish would have zero length (Ricker 1975).

[e] $Corr(x,y)$ is the correlation of parameter estimates x and y.

APPENDIX B
DATA FILE LISTING

B1.-Data files[a] used to estimate parameters of the Arctic grayling population in the Chena River in 1994.

Data file	Description
U002ALA4.DTA	Population and marking data (first event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 5 through 8 July 1994.
U002BLA4.DTA	Population and marking data (second event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 11 through 14 July 1994.
U001ELA4.DTA	Population and marking data (first event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 19 through 25 July 1994.
U001FLA4.DTA	Population and recapture data (second event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 26 through 29 July 1994.

[a] Data files have been archived at, and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.